



US009106021B2

(12) **United States Patent**  
**Patel et al.**

(10) **Patent No.:** **US 9,106,021 B2**  
(45) **Date of Patent:** **\*Aug. 11, 2015**

(54) **COMMUNICATION CONNECTOR WITH A PLURALITY OF PLUG INTERFACE CONTACTS**

(2013.01); **H01R 13/6658** (2013.01); **H01R 24/64** (2013.01); **H05K 1/0228** (2013.01); **H05K 1/0239** (2013.01); **Y10T 29/4913** (2015.01)

(71) Applicant: **Panduit Corp.**, Tinley Park, IL (US)

(58) **Field of Classification Search**

USPC ..... 439/676, 625–626, 620.22, 620.23  
See application file for complete search history.

(72) Inventors: **Satish I. Patel**, Roselle, IL (US); **Robert E. Fransen**, Tinley Park, IL (US); **Frank M. Straka**, Chicago, IL (US); **Melanie M. Hagar**, Park Forest, IL (US)

(56) **References Cited**

#### U.S. PATENT DOCUMENTS

(73) Assignee: **Panduit Corp.**, Tinley Park, IL (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

2,476,886	A	7/1949	Miller et al.
3,949,180	A	4/1976	Ojima et al.
4,080,027	A	3/1978	Benasutti
4,274,691	A	6/1981	Abernethy et al.
4,662,702	A	5/1987	Furuya
5,163,835	A	11/1992	Morlion et al.
5,224,884	A	7/1993	Singer et al.
5,230,632	A	7/1993	Baumberger et al.
5,240,420	A	8/1993	Roberts
5,716,237	A	2/1998	Conorich et al.
5,788,515	A	8/1998	Mitra et al.

(Continued)

(21) Appl. No.: **14/170,988**

(22) Filed: **Feb. 3, 2014**

(65) **Prior Publication Data**

US 2014/0148057 A1 May 29, 2014

#### FOREIGN PATENT DOCUMENTS

EP	0645843	A2	3/1995
WO	2008060272	A1	5/2008
WO	2008076813	A2	6/2008

*Primary Examiner* — Chandrika Prasad

(74) *Attorney, Agent, or Firm* — Christopher S. Clancy; Yuri Astvatsaturov

#### Related U.S. Application Data

(63) Continuation of application No. 13/425,130, filed on Mar. 20, 2012, now Pat. No. 8,641,452.

(60) Provisional application No. 61/466,201, filed on Mar. 22, 2011.

(51) **Int. Cl.**

**H01R 13/66** (2006.01)

**H01R 13/6461** (2011.01)

**H01R 13/6466** (2011.01)

**H01R 24/64** (2011.01)

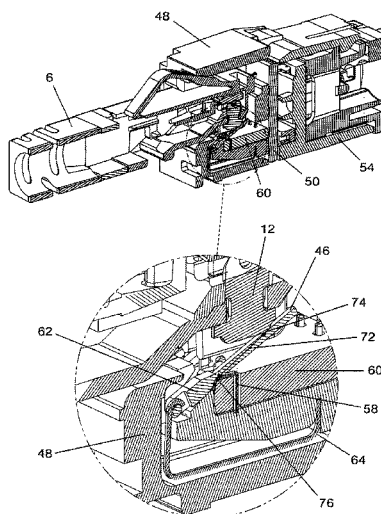
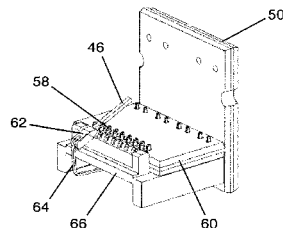
**H05K 1/02** (2006.01)

(57)

#### ABSTRACT

A communication jack which includes a housing with an aperture for receiving a communication plug, and a circuit board at least partially within the housing. The circuit board includes crosstalk compensation elements. A plurality of plug interface contacts are connected to the circuit board. At least one of the plurality of plug interface contacts includes a contact element layered with at least one spring element.

**28 Claims, 43 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

6,010,367 A 1/2000 Wu  
 6,089,923 A 7/2000 Phommachanh  
 6,106,335 A 8/2000 Merchant et al.  
 6,176,742 B1 \* 1/2001 Arnett et al. .... 439/620.23  
 6,360,437 B1 3/2002 Fukumoto et al.  
 6,530,810 B2 \* 3/2003 Goodrich et al. .... 439/676  
 6,767,257 B2 7/2004 Arnett et al.

6,786,776 B2 \* 9/2004 Itano et al. .... 439/676  
 7,125,288 B2 10/2006 Schilling  
 7,294,025 B1 \* 11/2007 Chen .... 439/676  
 7,367,849 B2 5/2008 Wang et al.  
 RE41,699 E 9/2010 Itano et al.  
 7,824,231 B2 \* 11/2010 Marti et al. .... 439/676  
 8,425,255 B2 \* 4/2013 Erickson et al. .... 439/620.22  
 8,641,452 B2 \* 2/2014 Patel et al. .... 439/620.23  
 2012/0052734 A1 3/2012 Fukuda et al.

\* cited by examiner

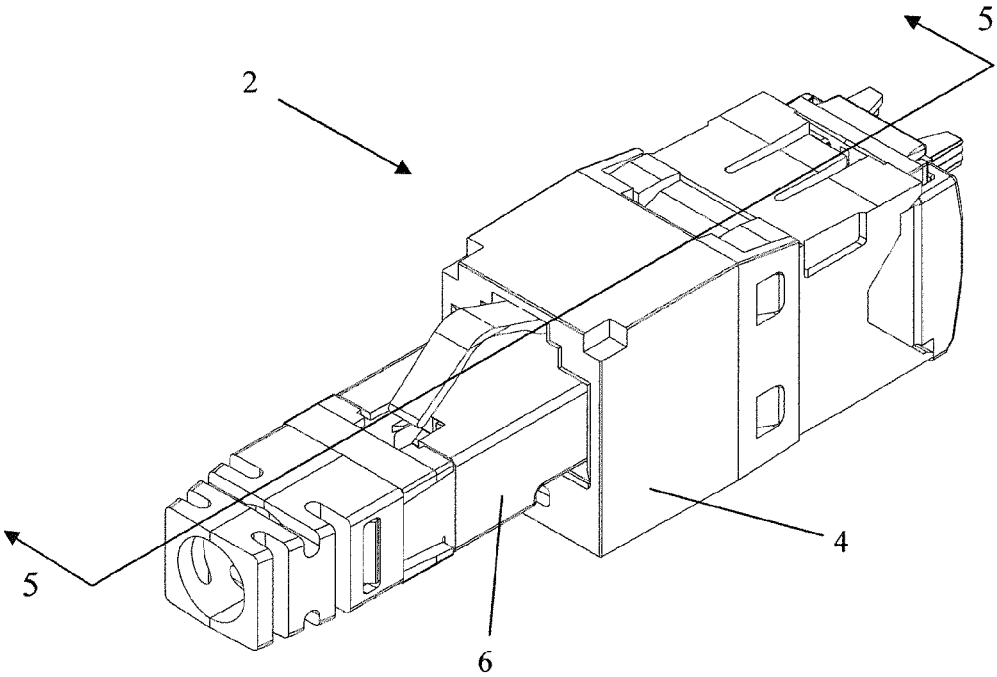


FIG. 1

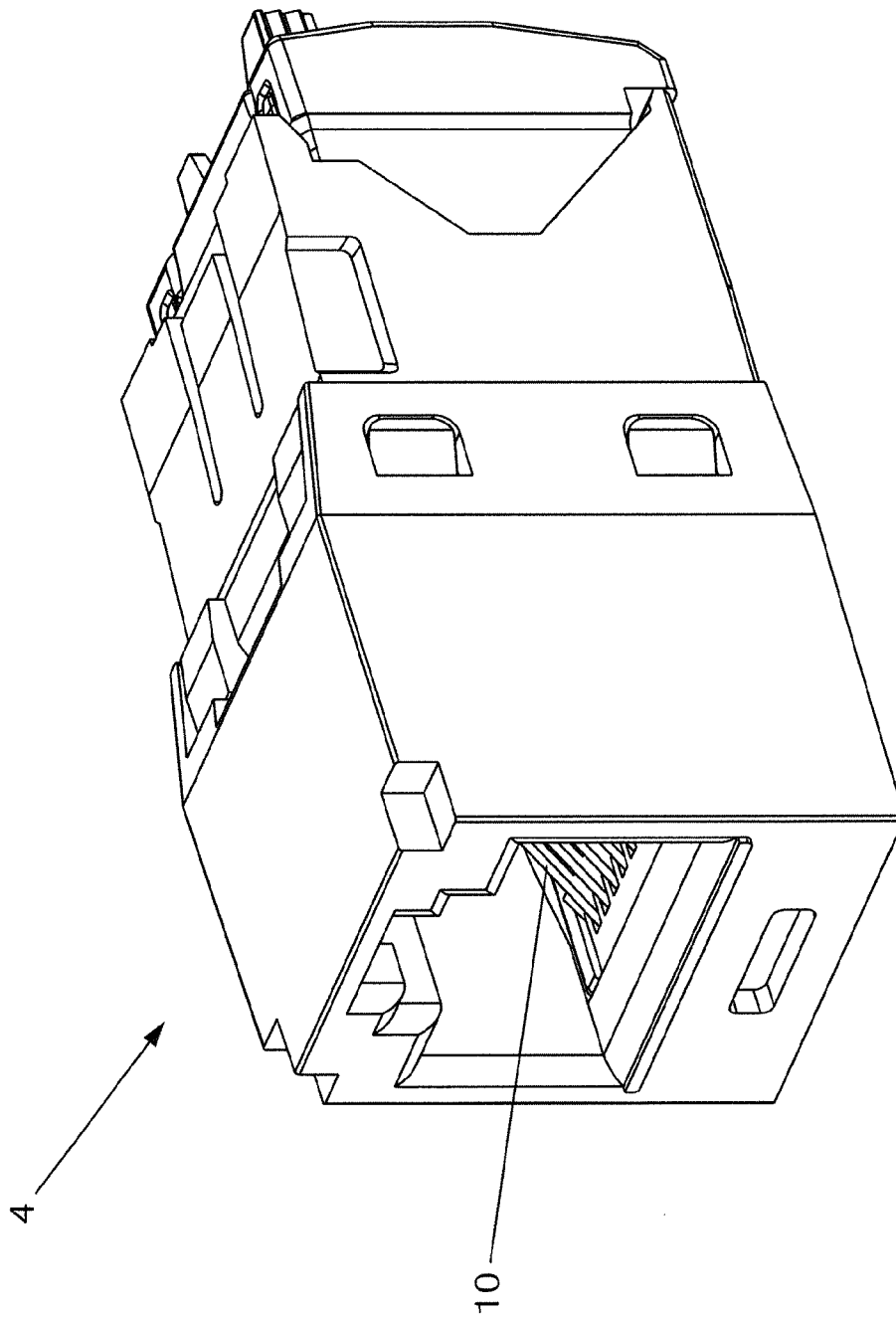


FIG. 2

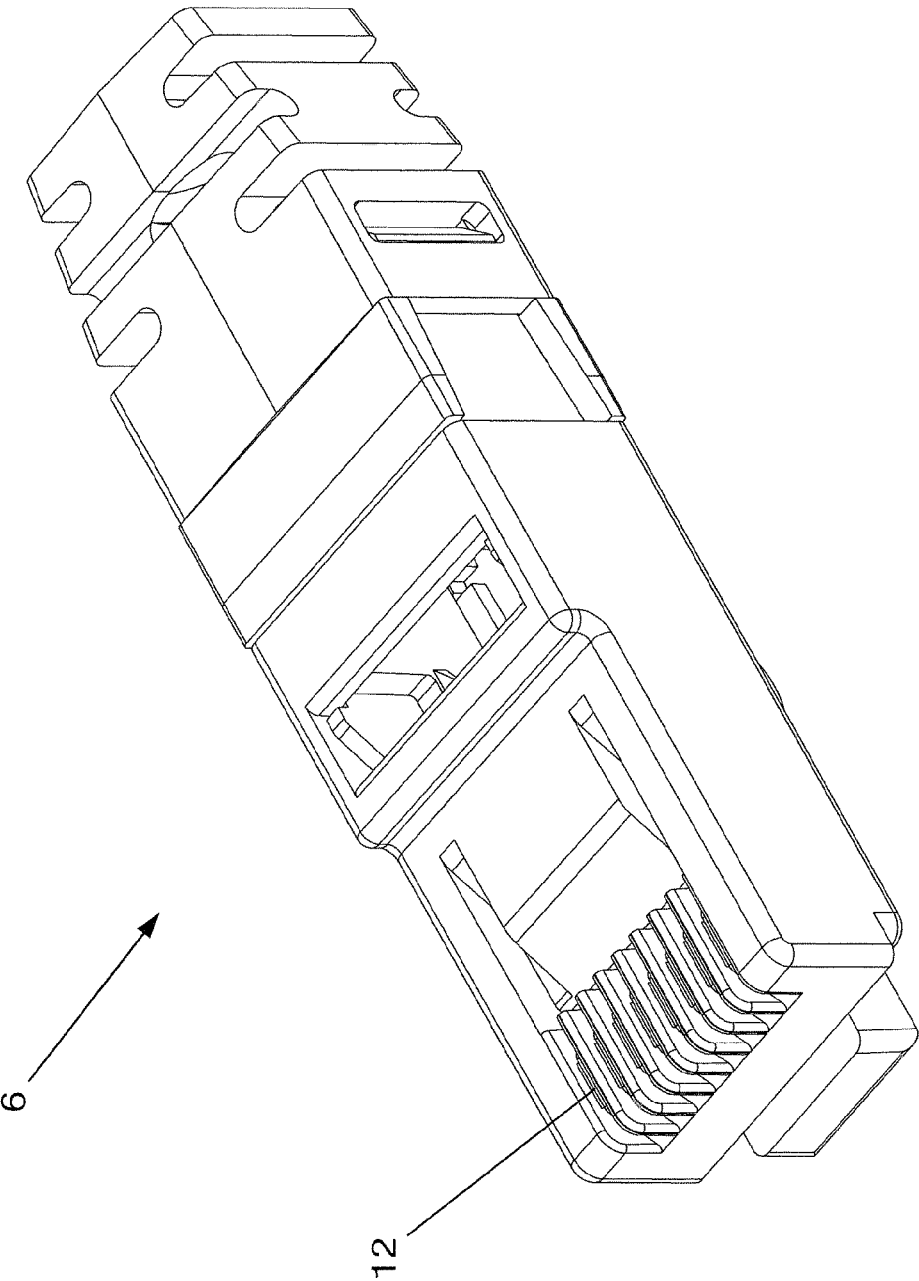


FIG.3

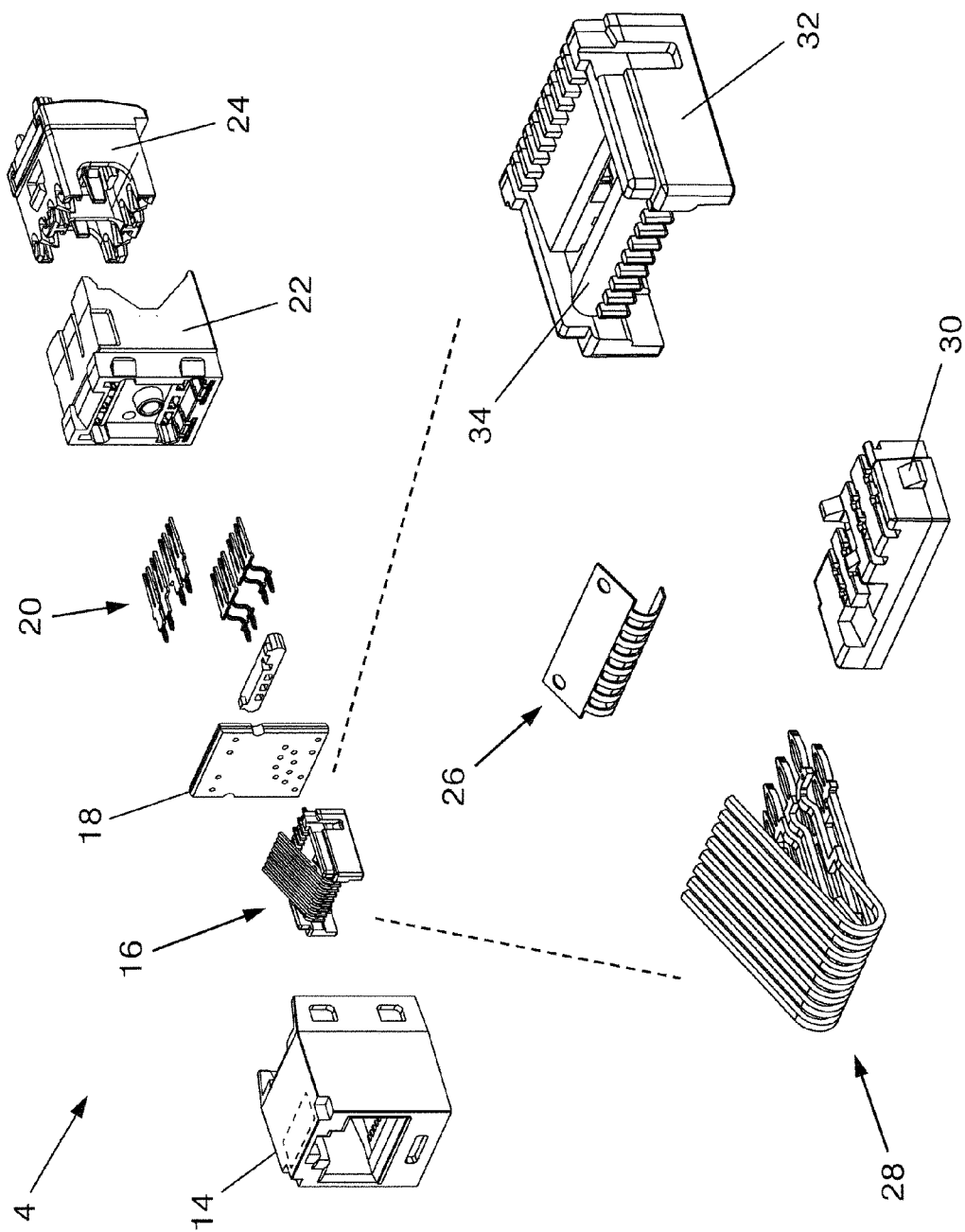


FIG. 4

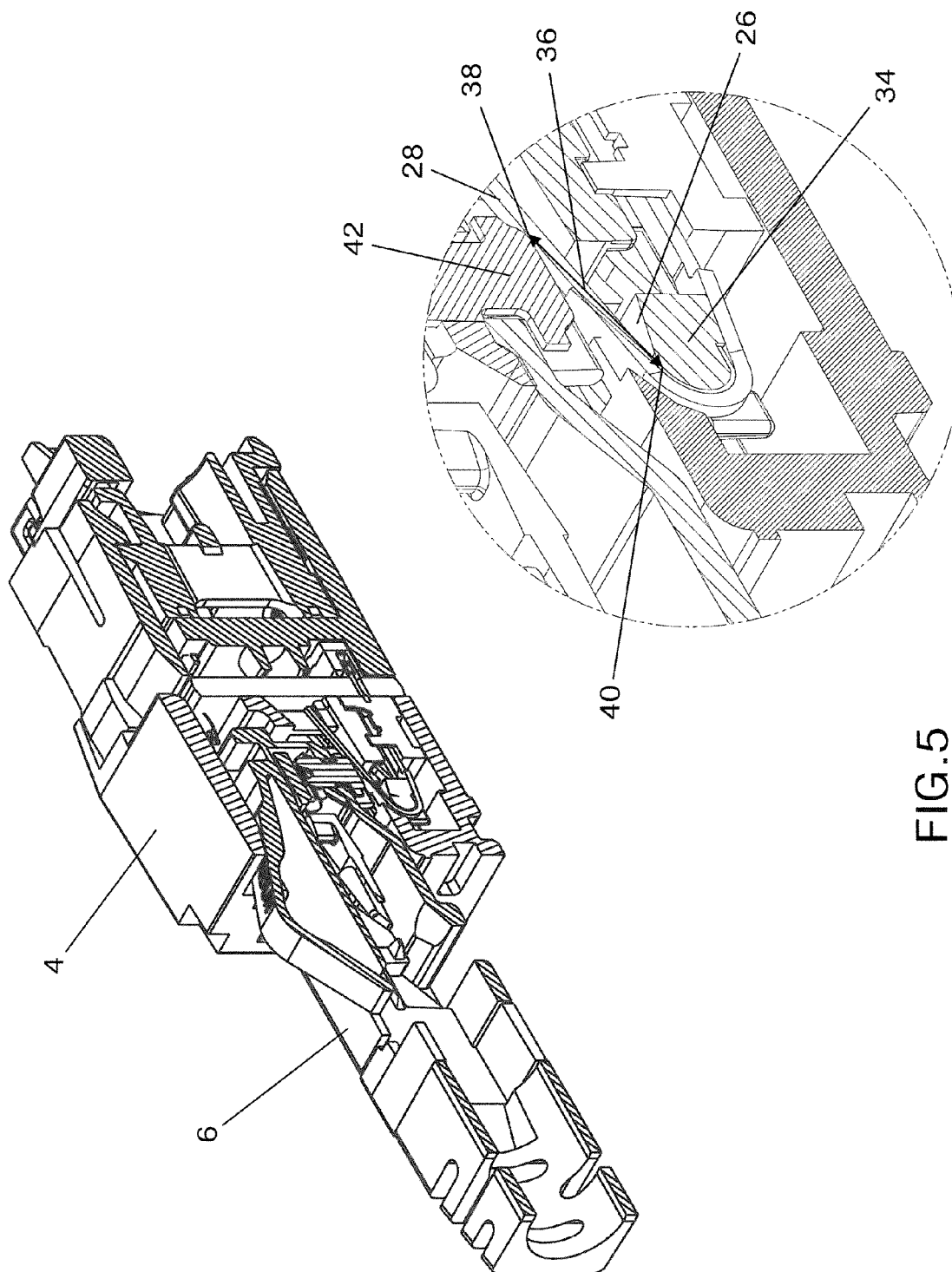


FIG. 5

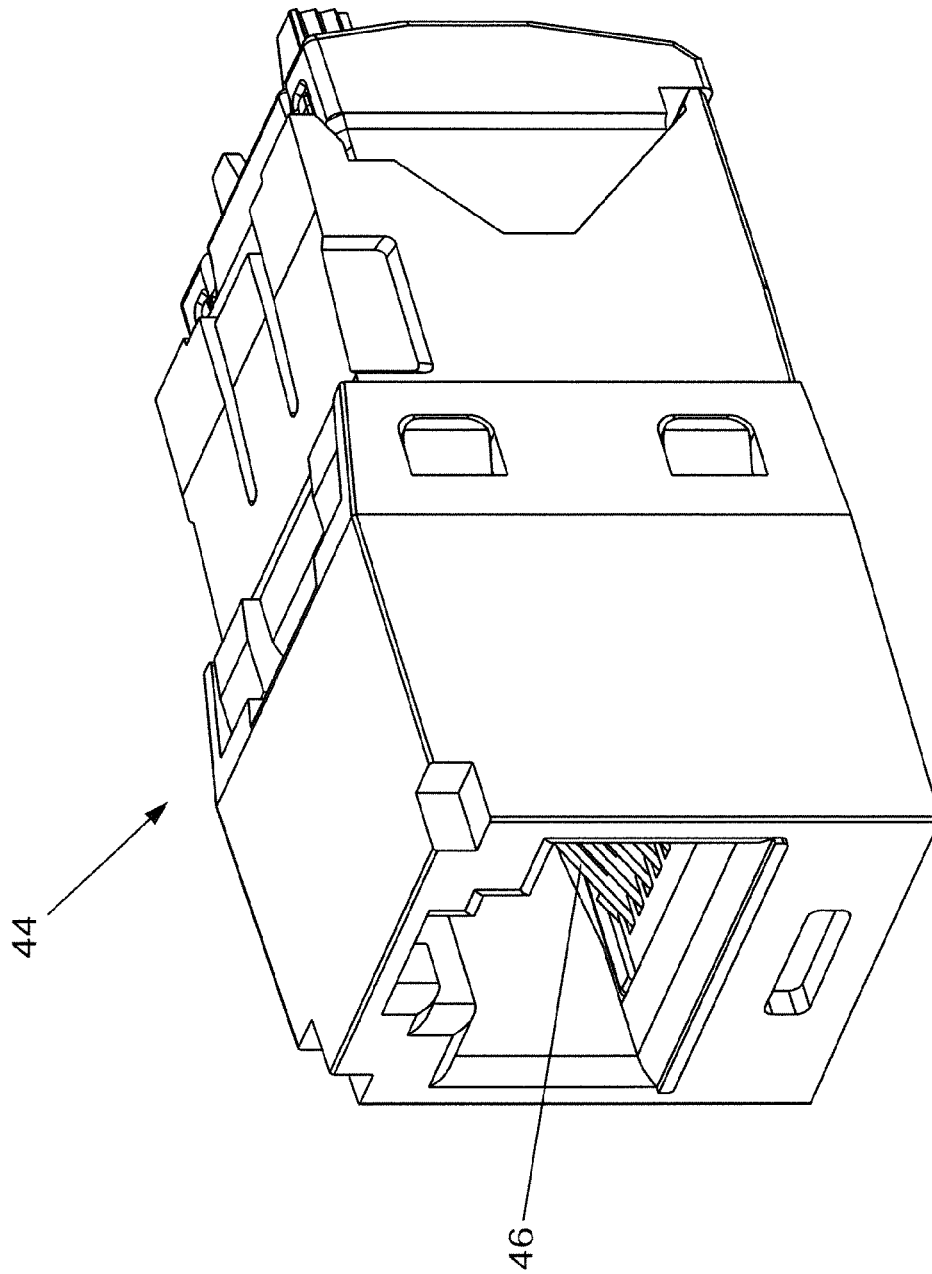
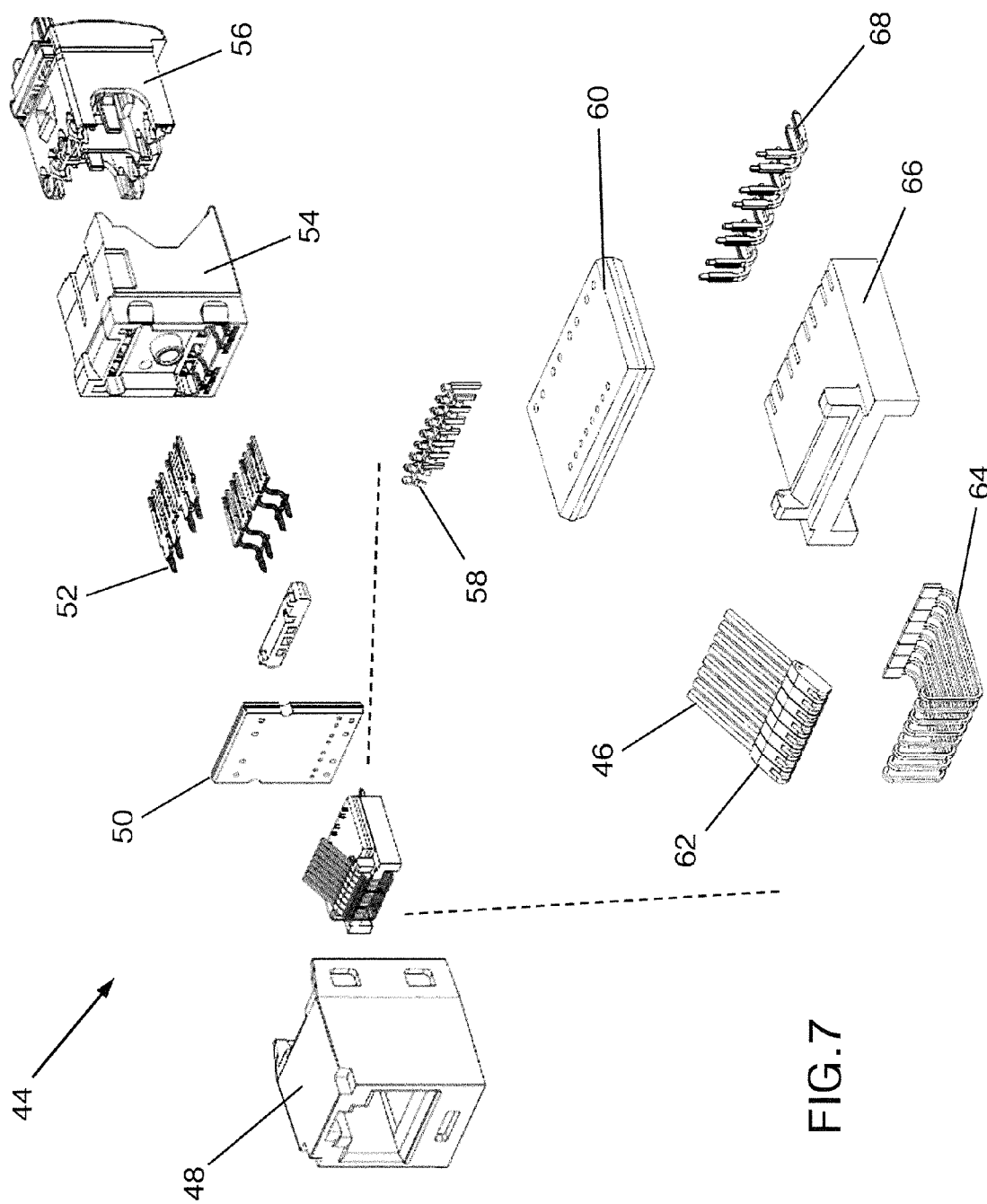


FIG. 6





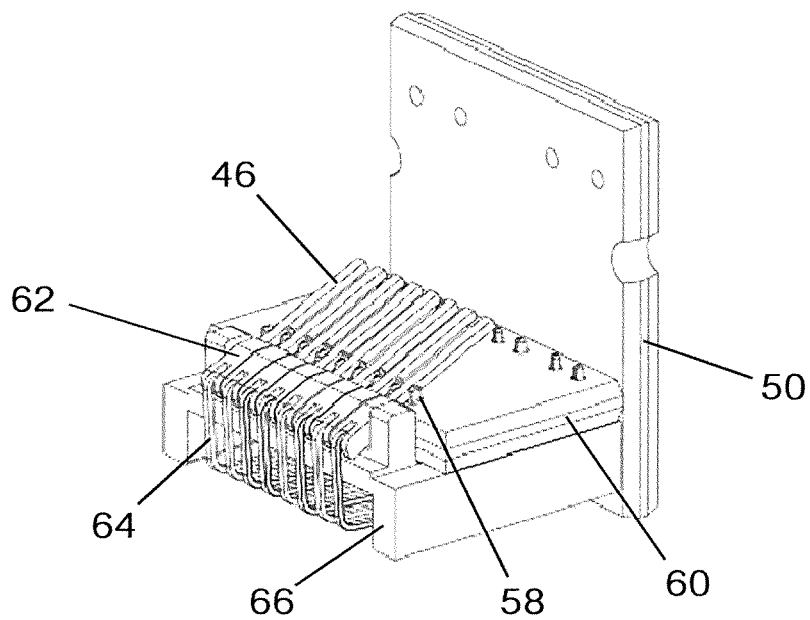


FIG. 8

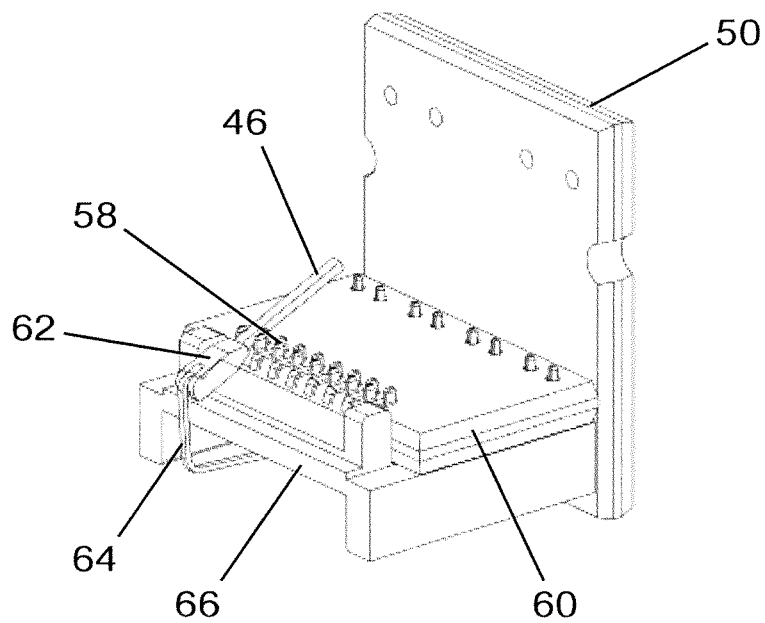


FIG. 9

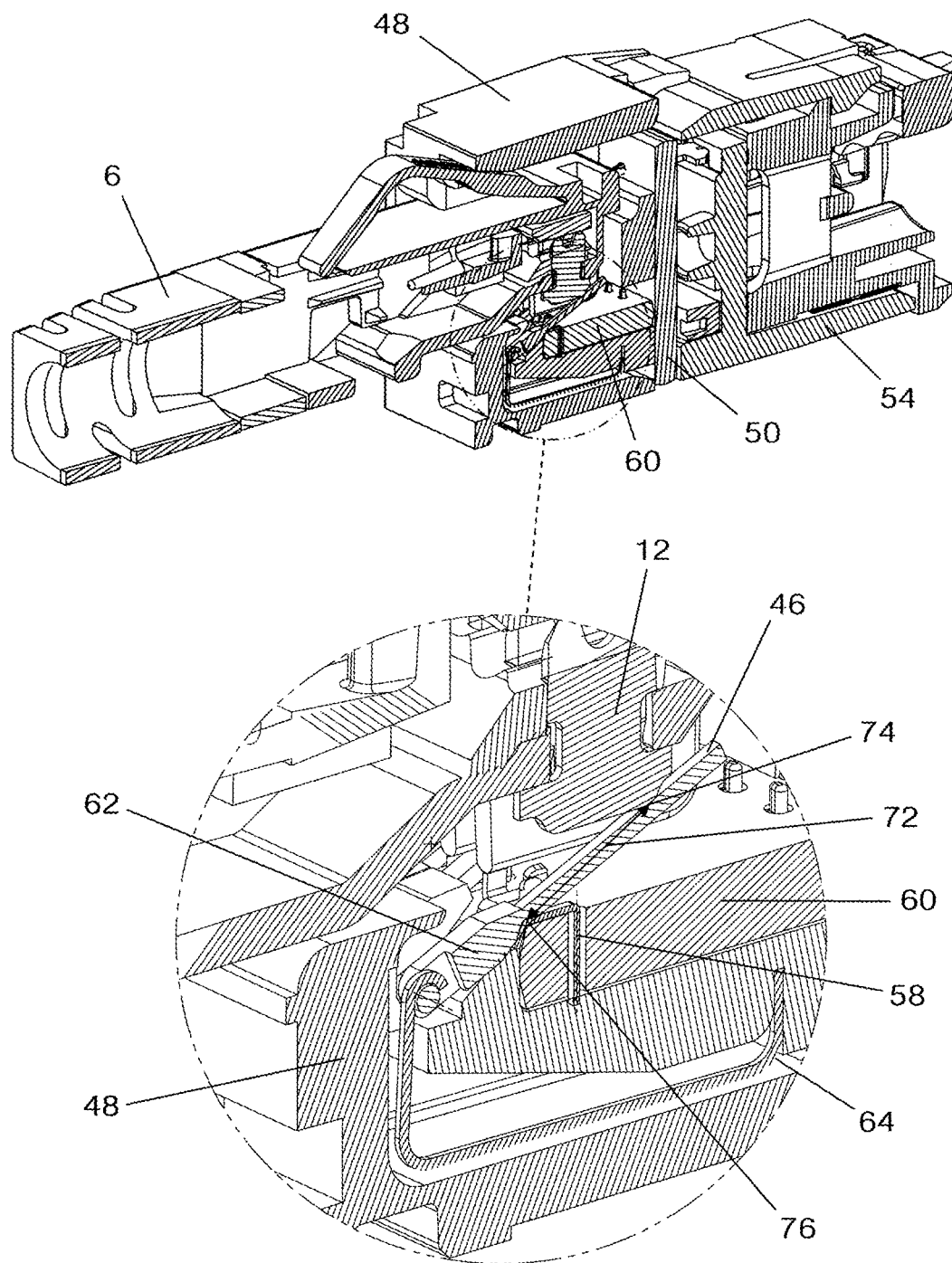


FIG.10

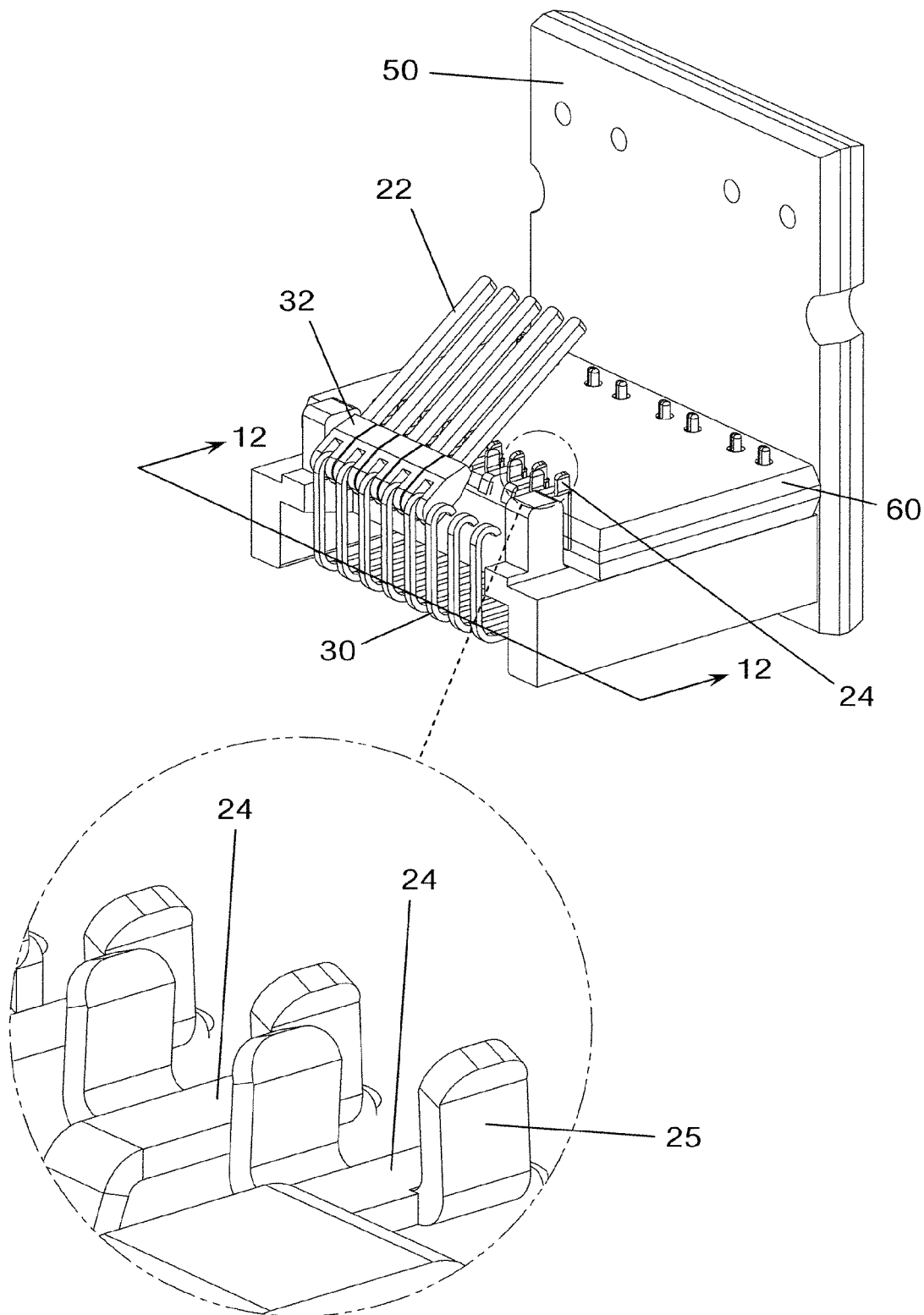


FIG. 11

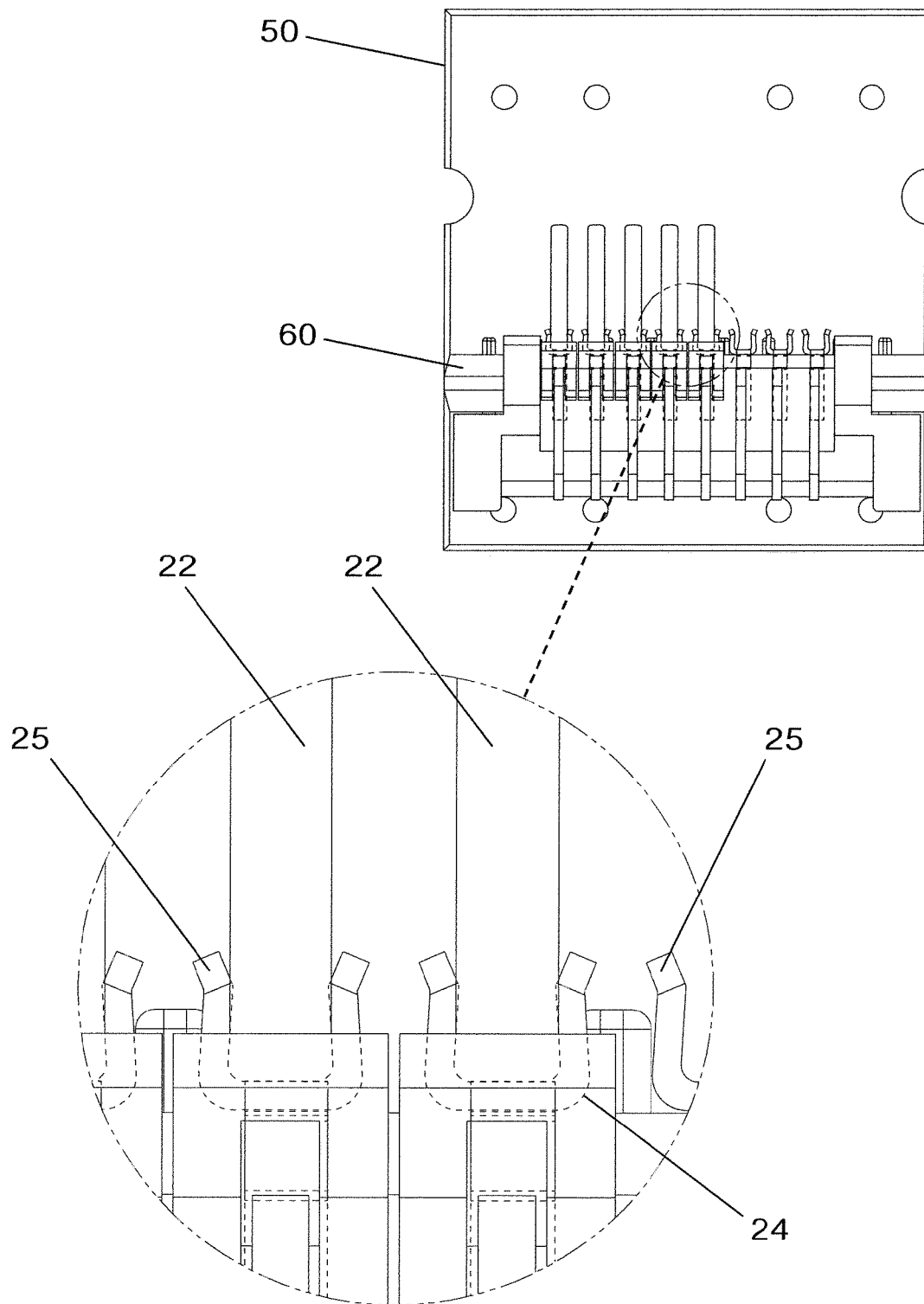


FIG.12

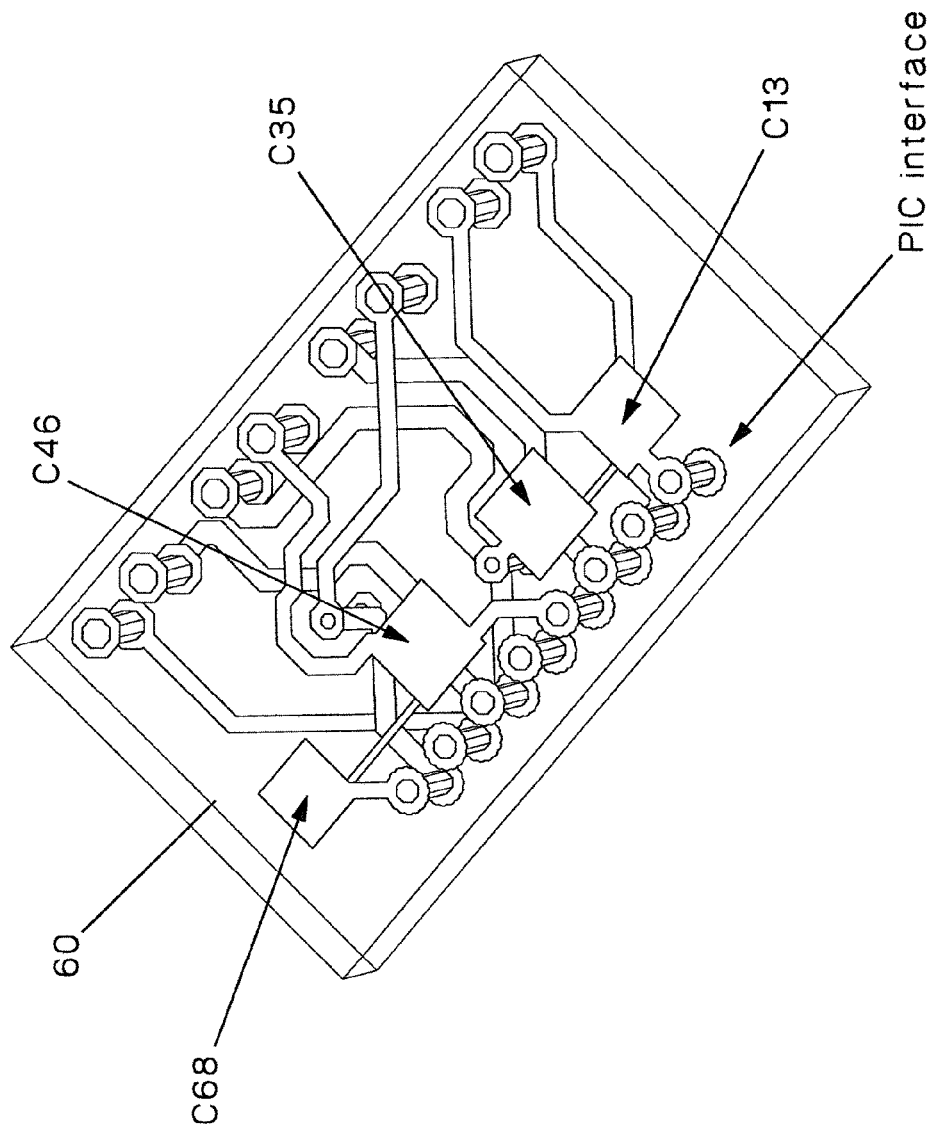


FIG. 13A

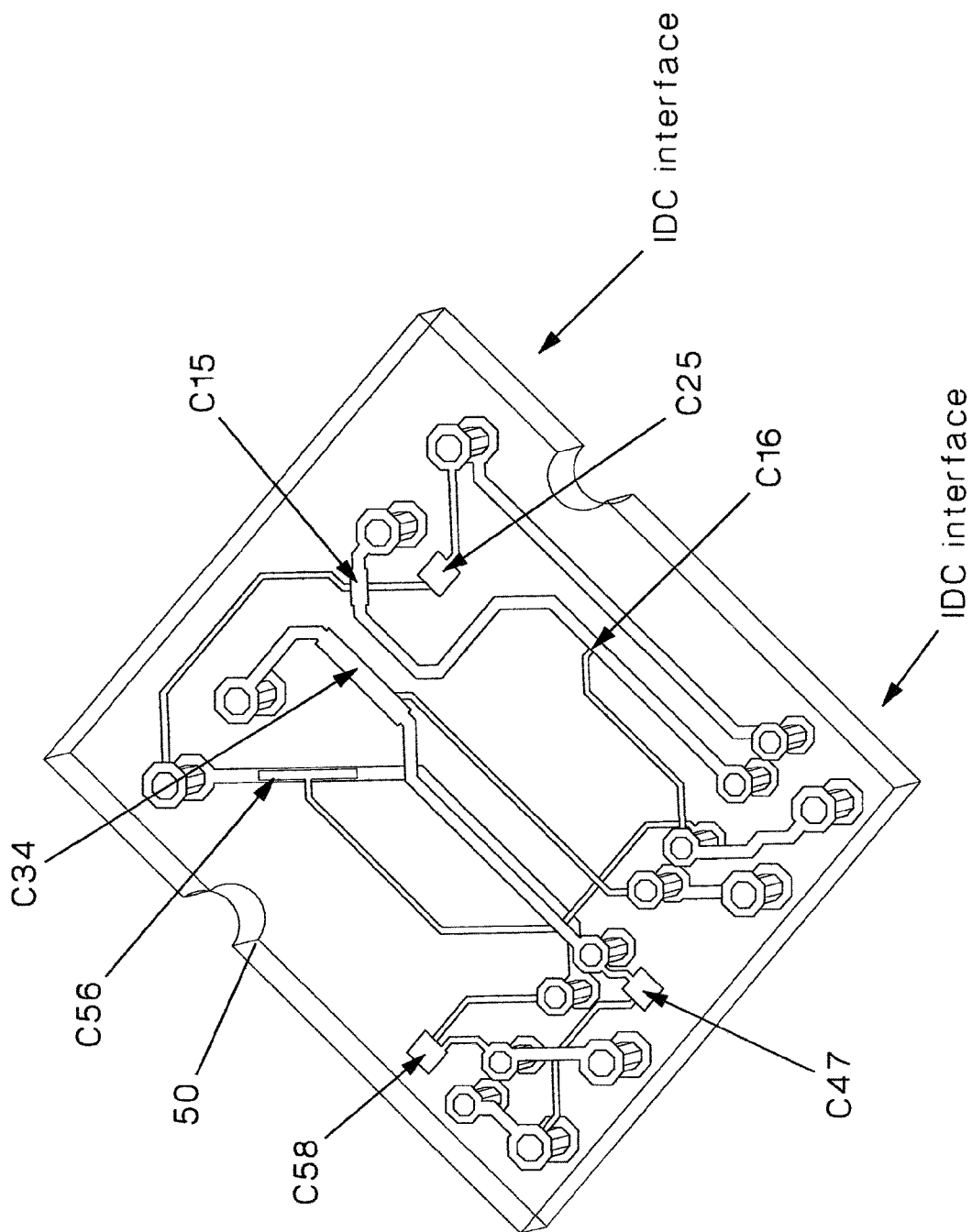


FIG. 13B

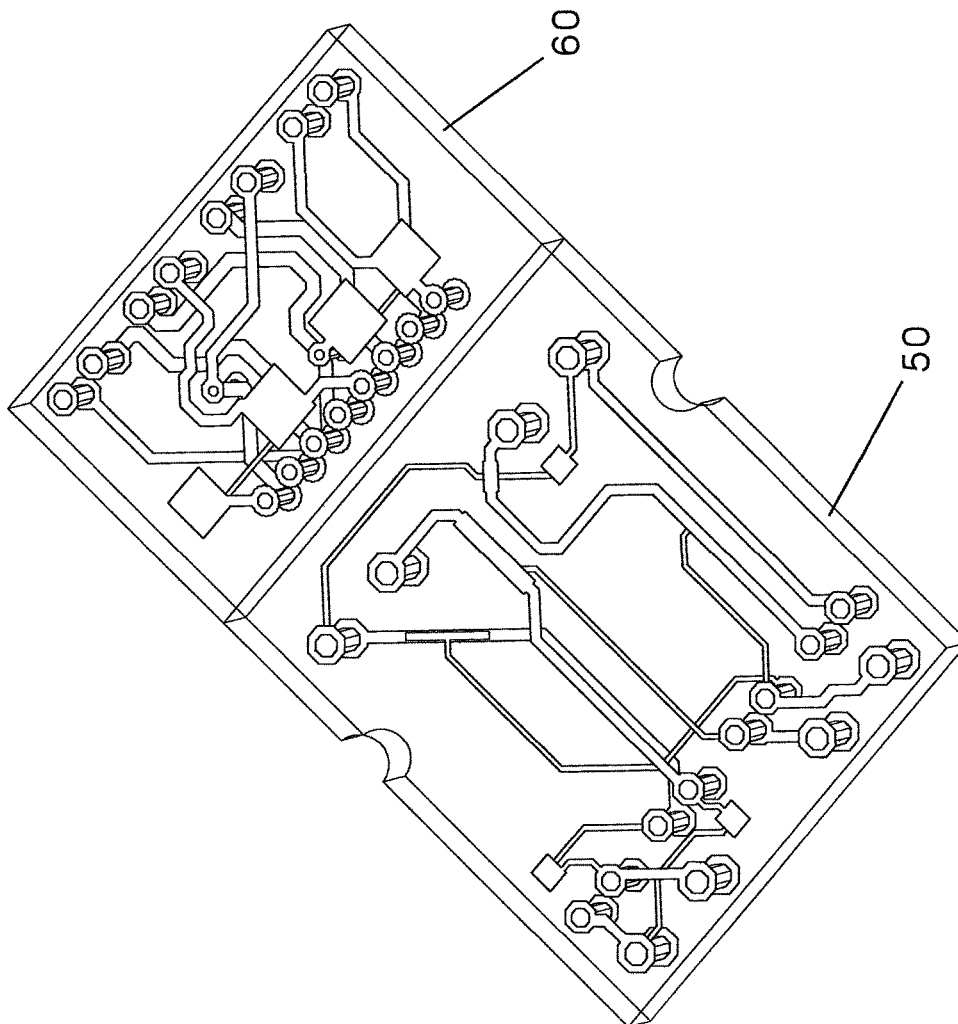


FIG. 14



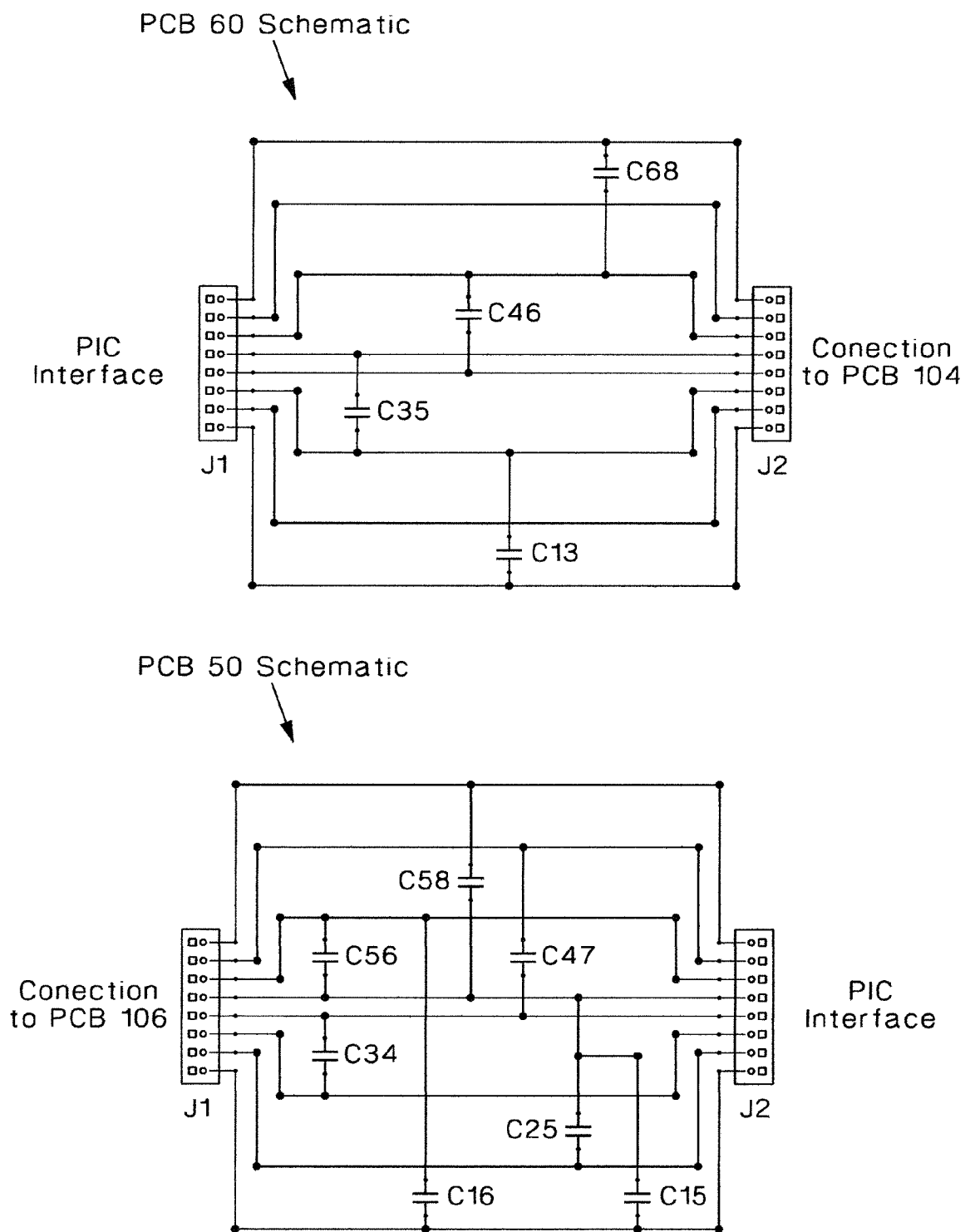


FIG.15

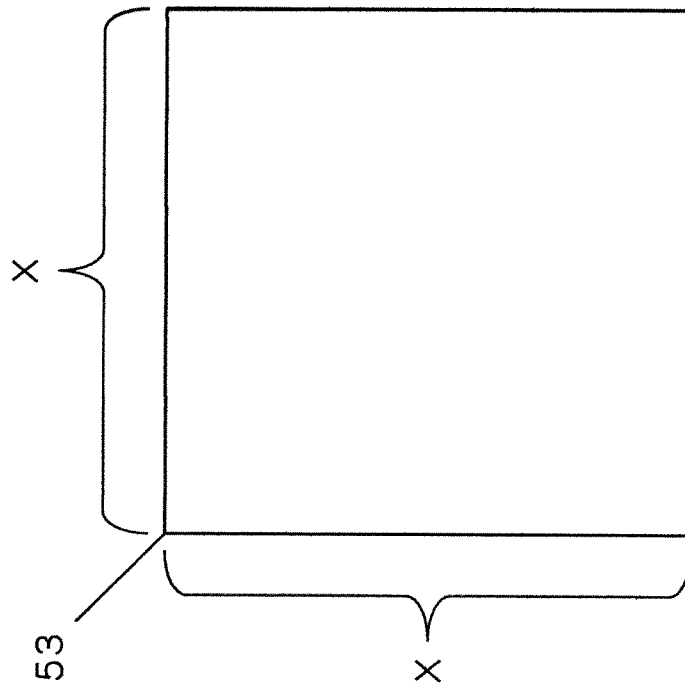
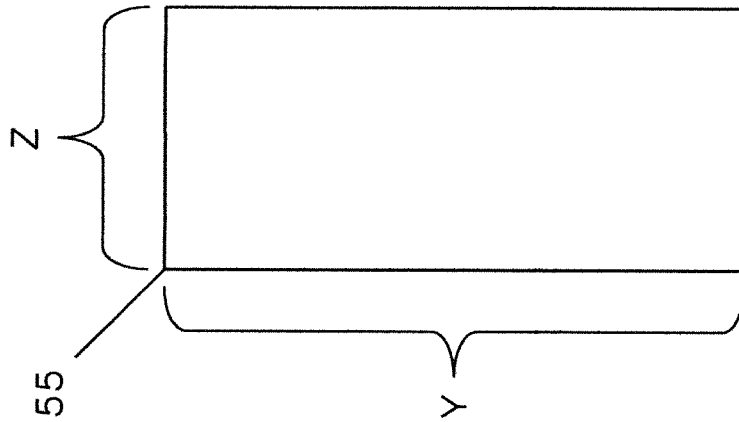


FIG.16

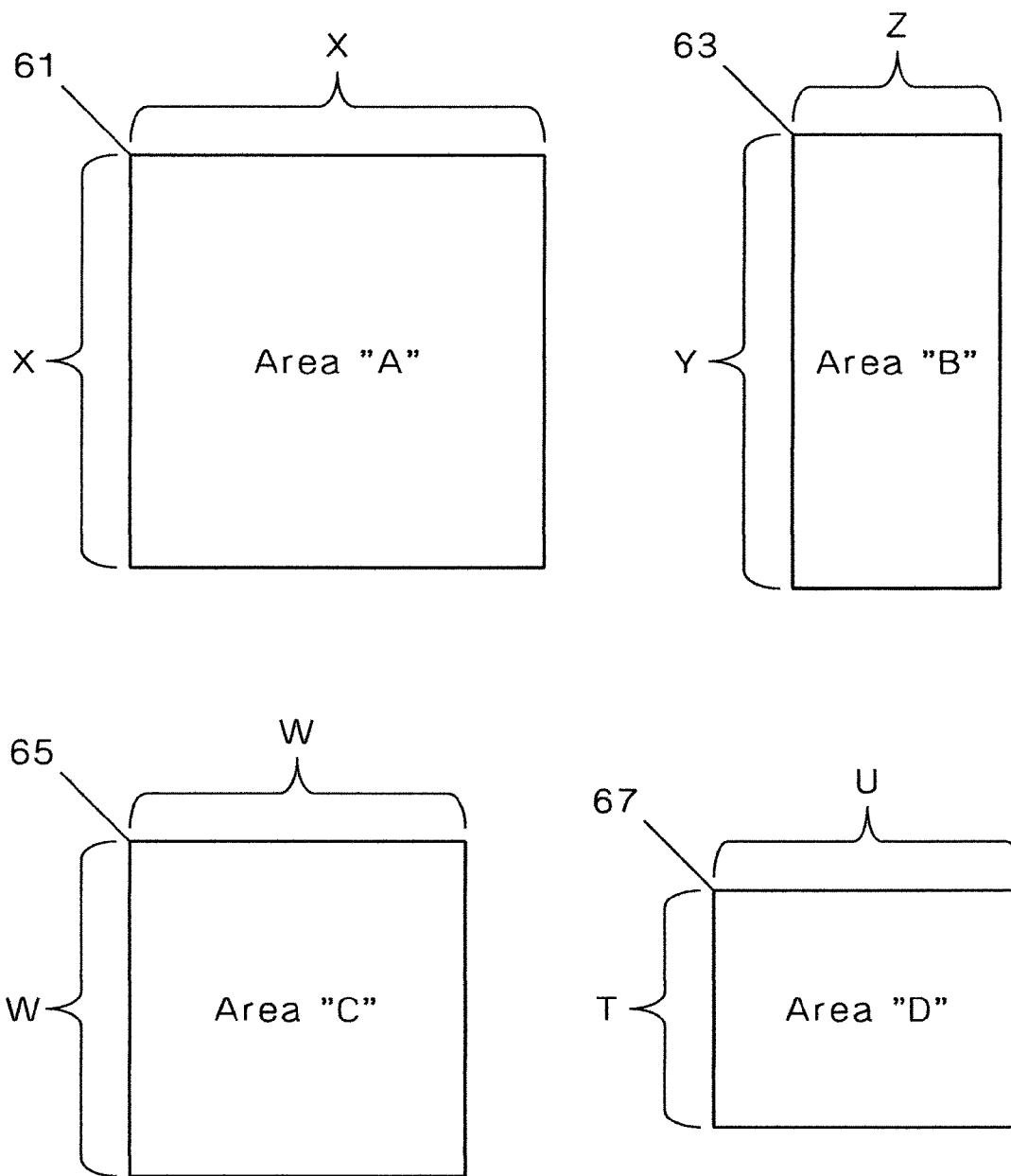


FIG.17

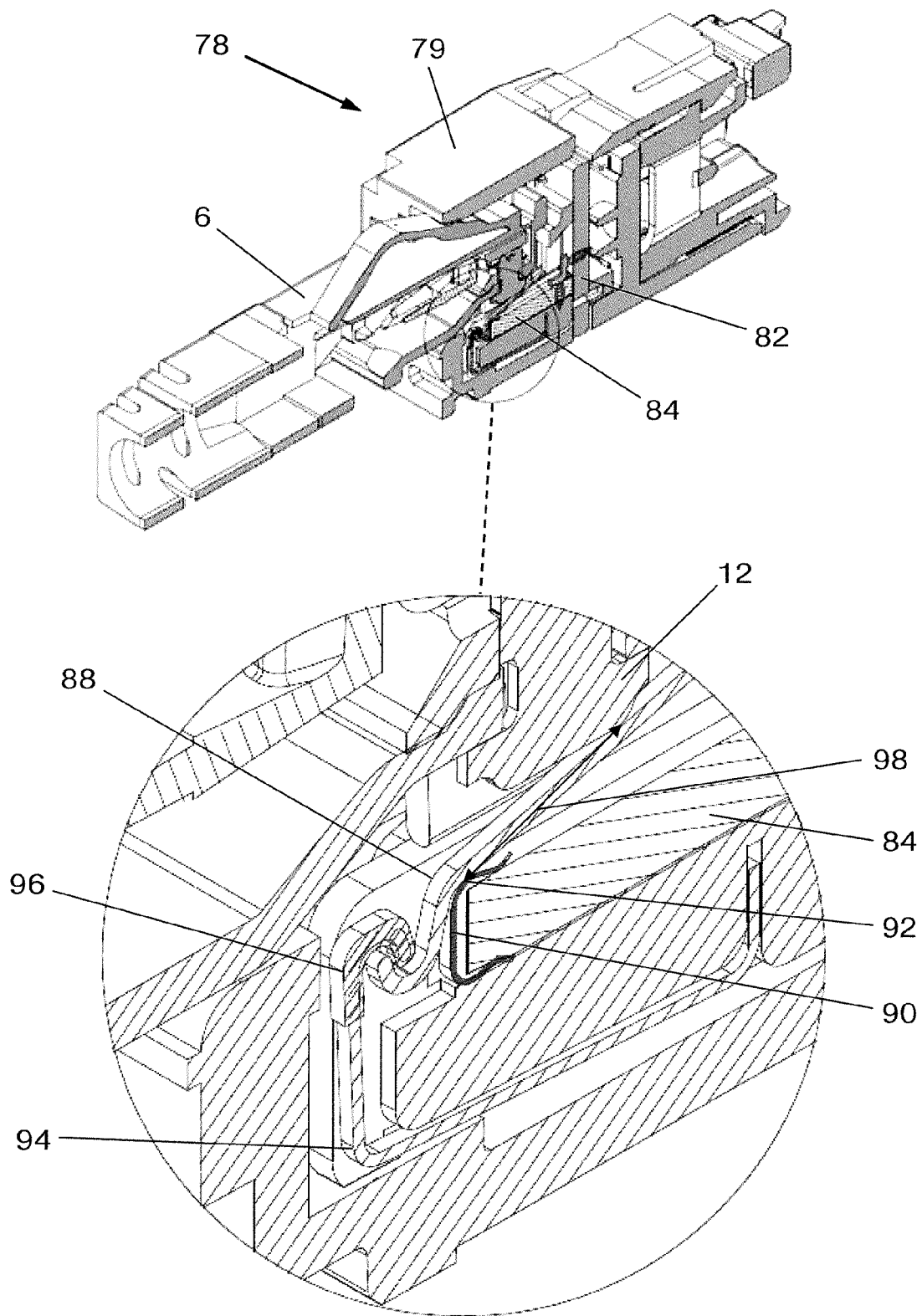


FIG.18

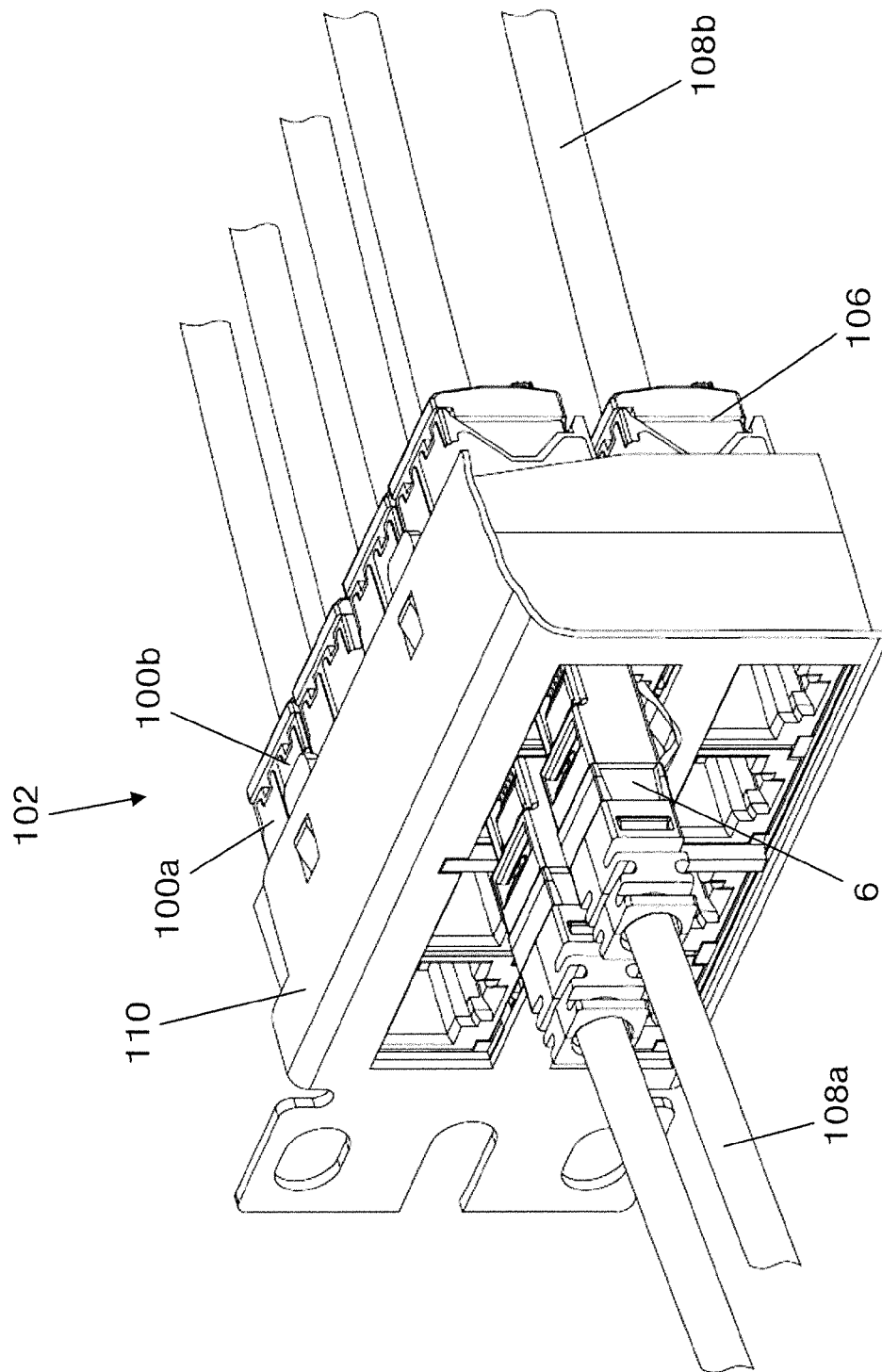


FIG. 19

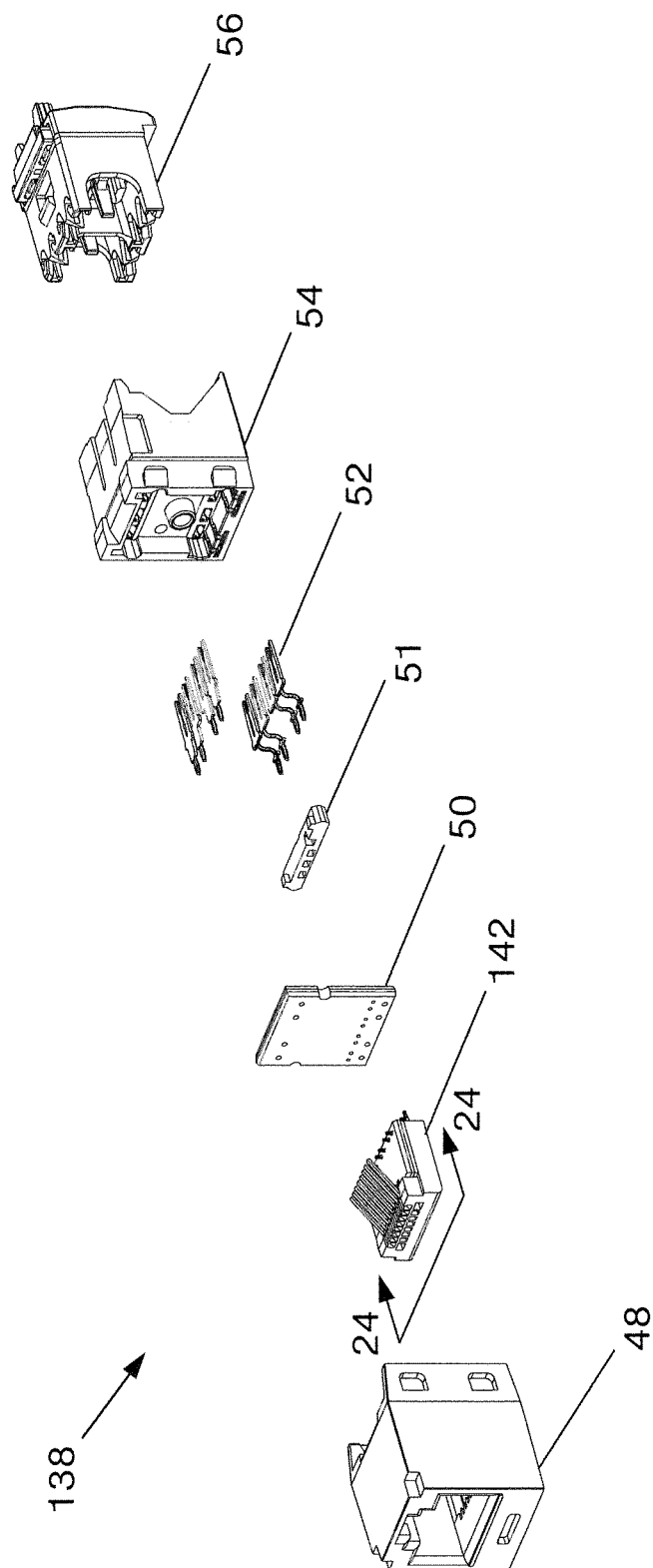


FIG.20

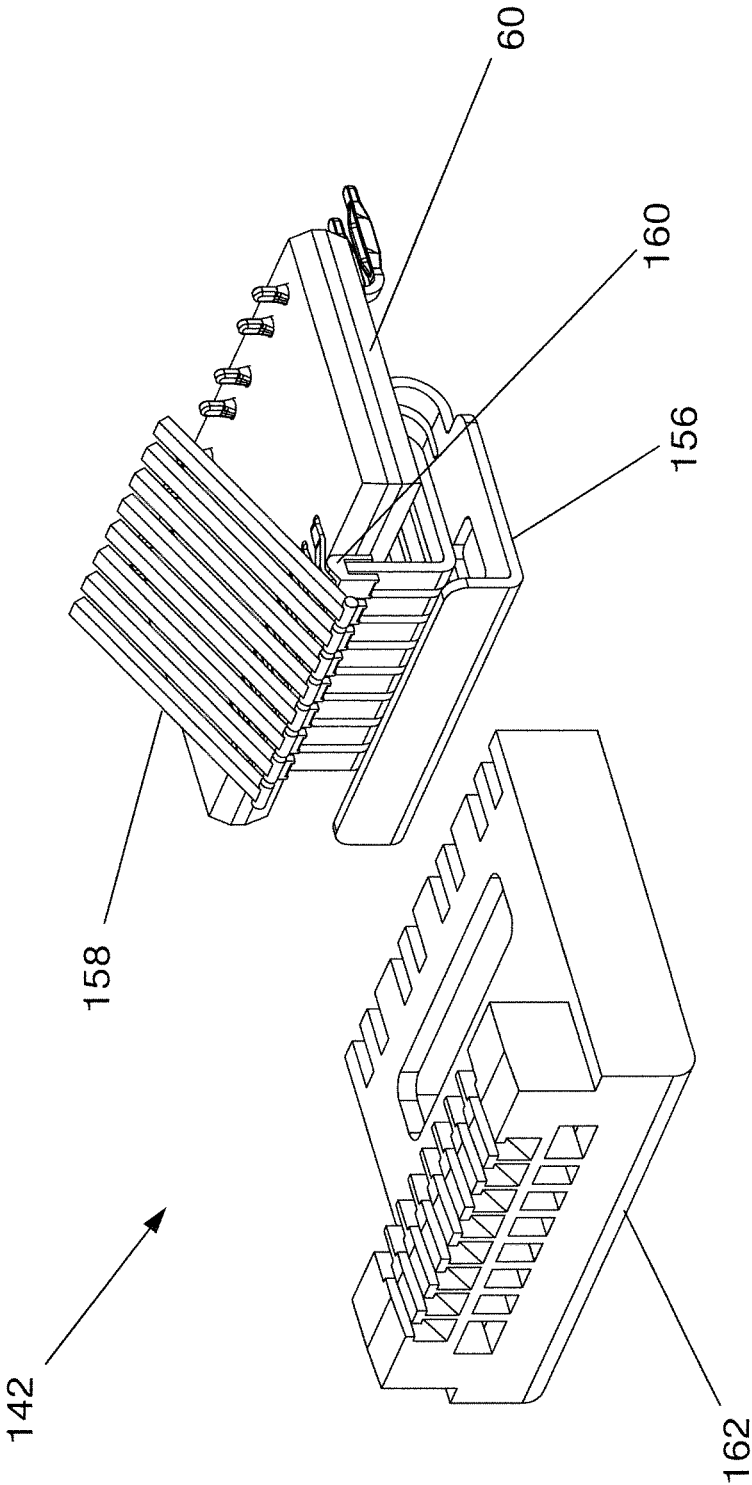


FIG.21

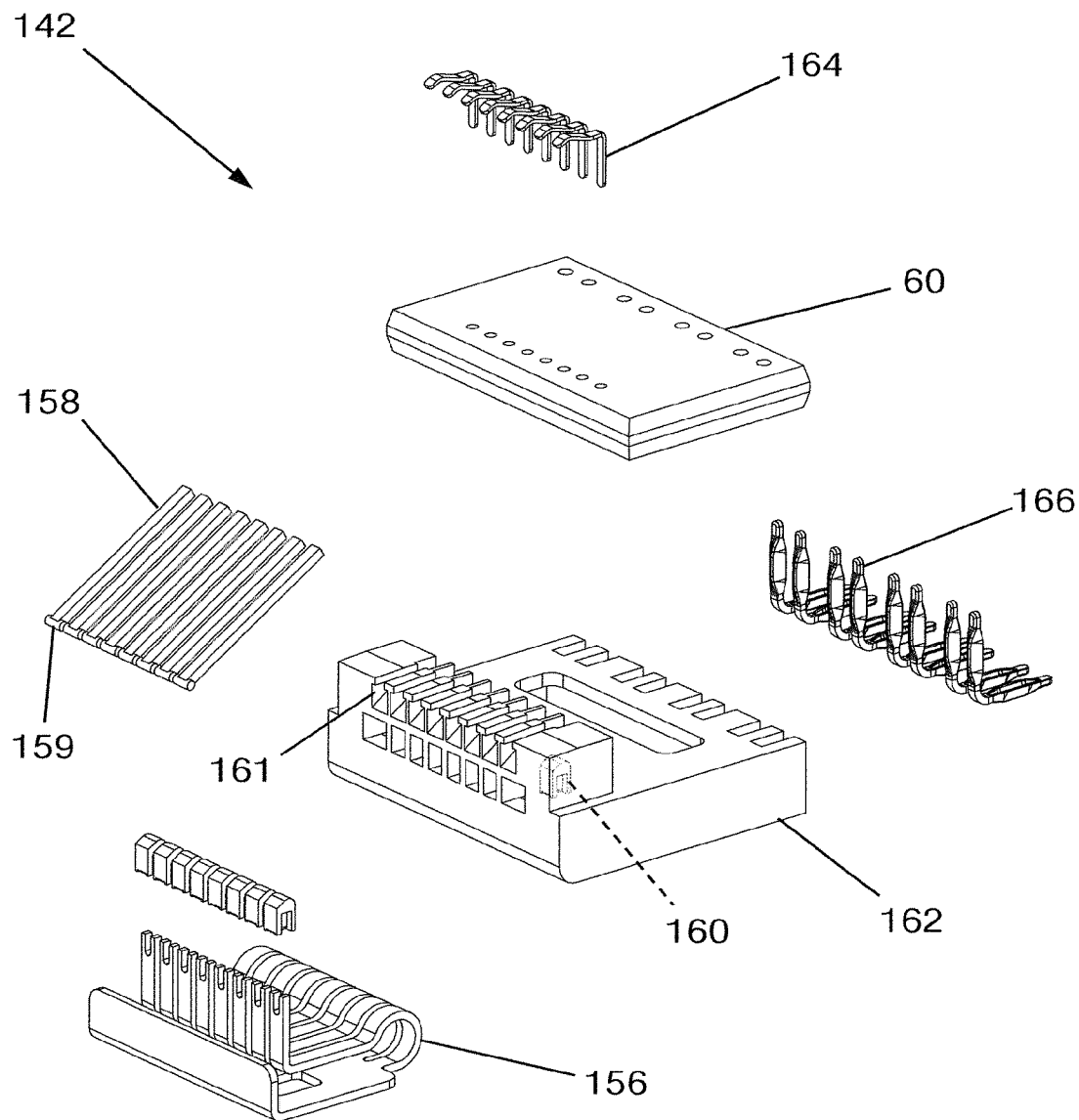


FIG.22



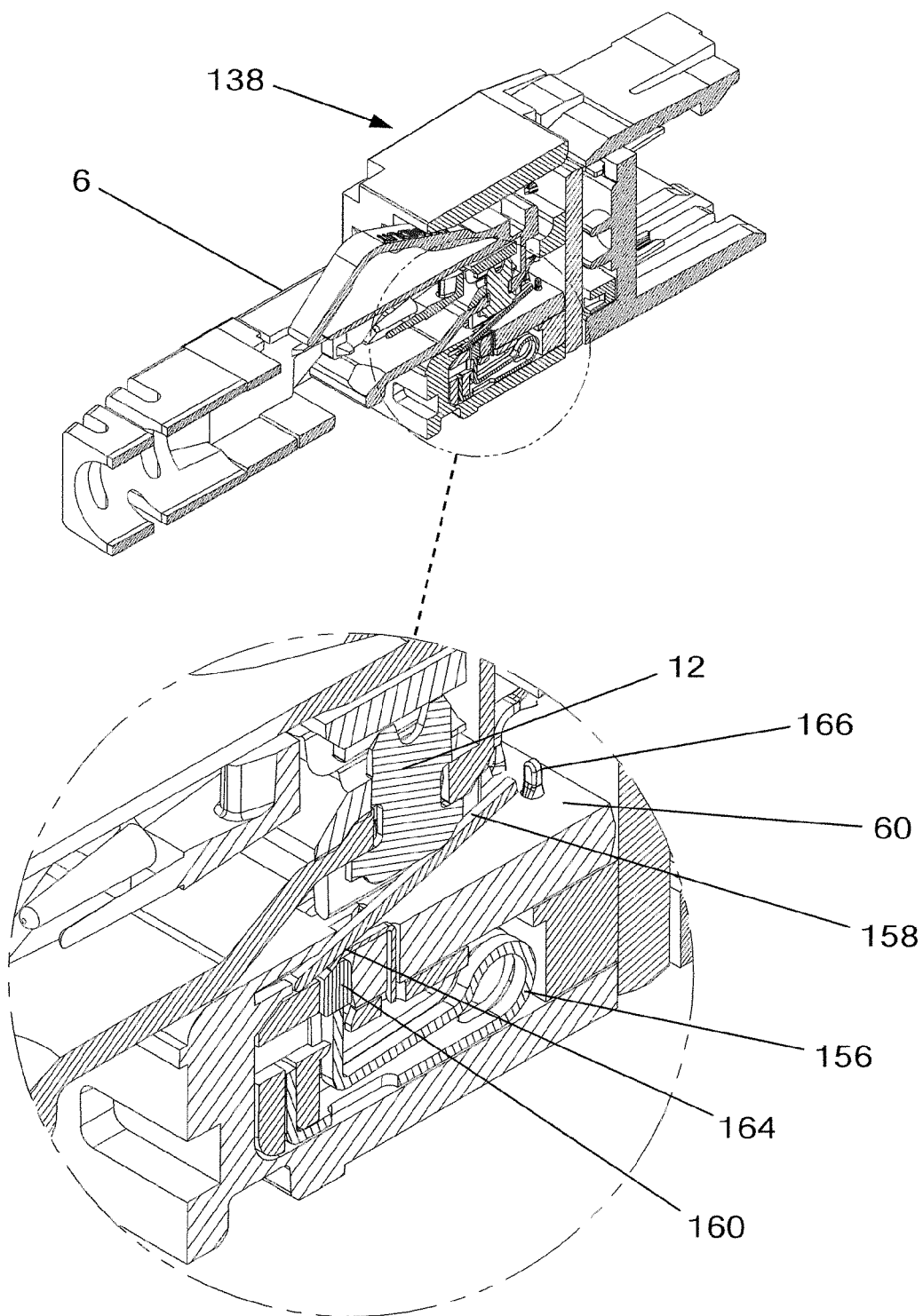


FIG.23

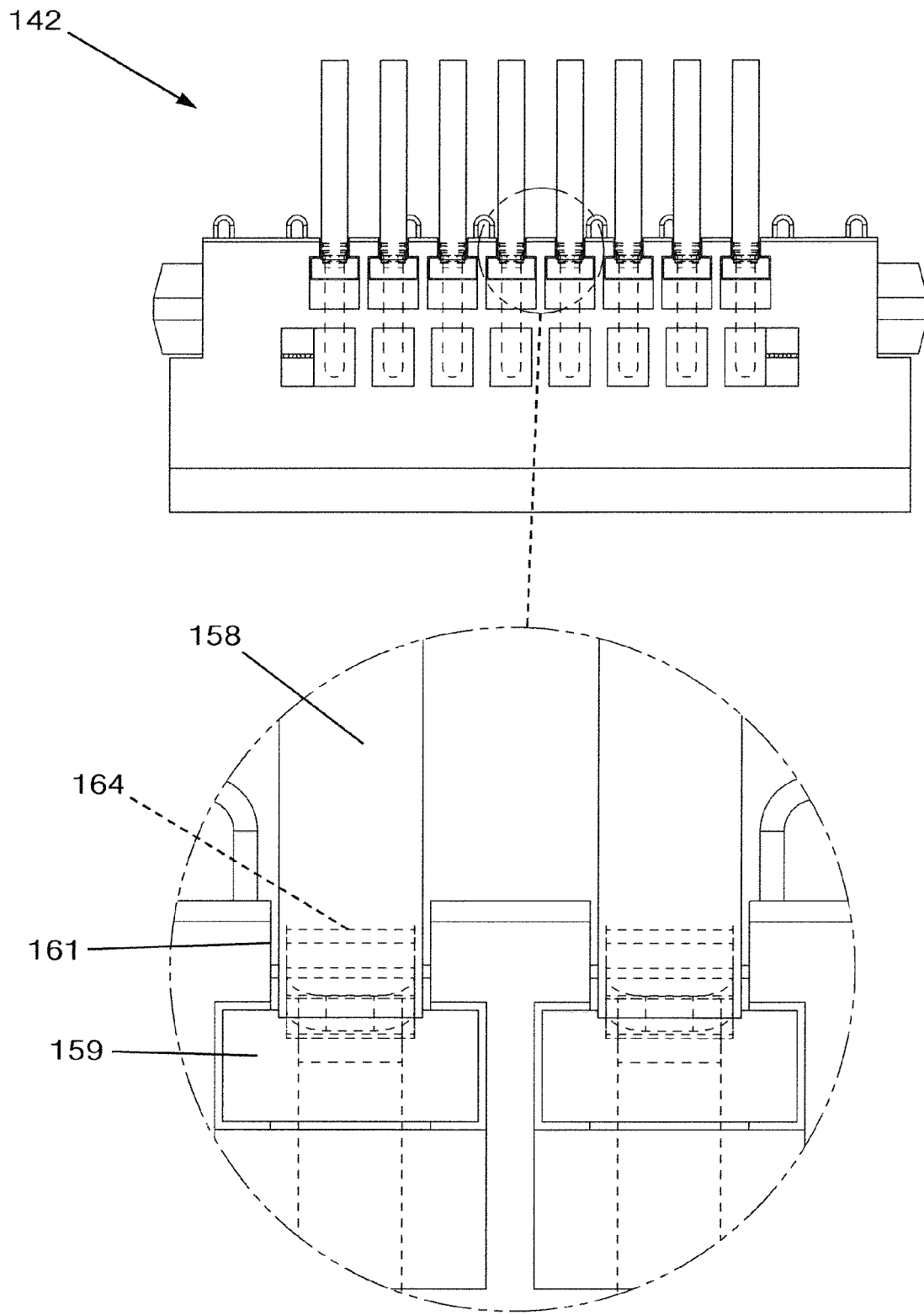


FIG.24

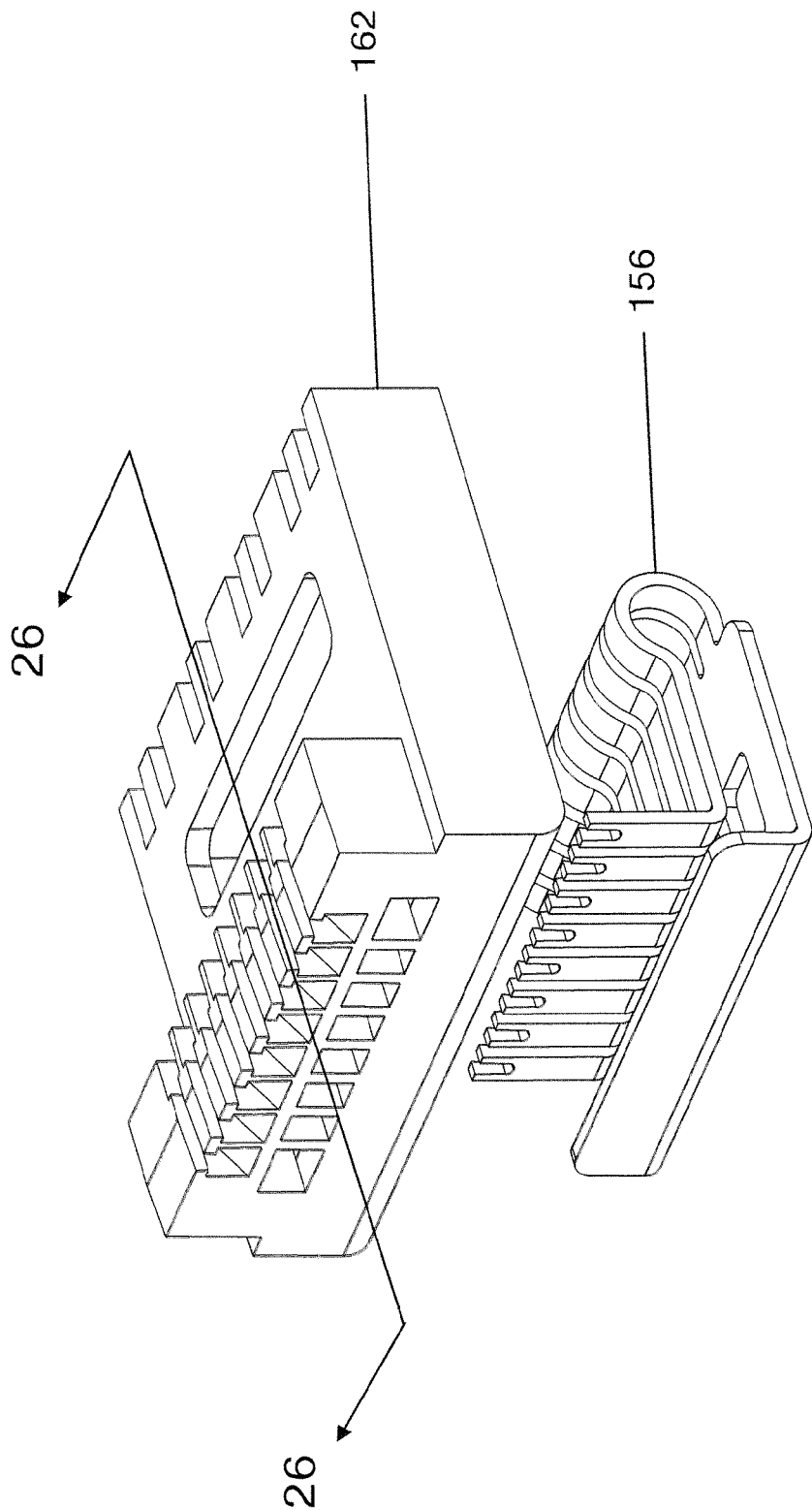


FIG. 25

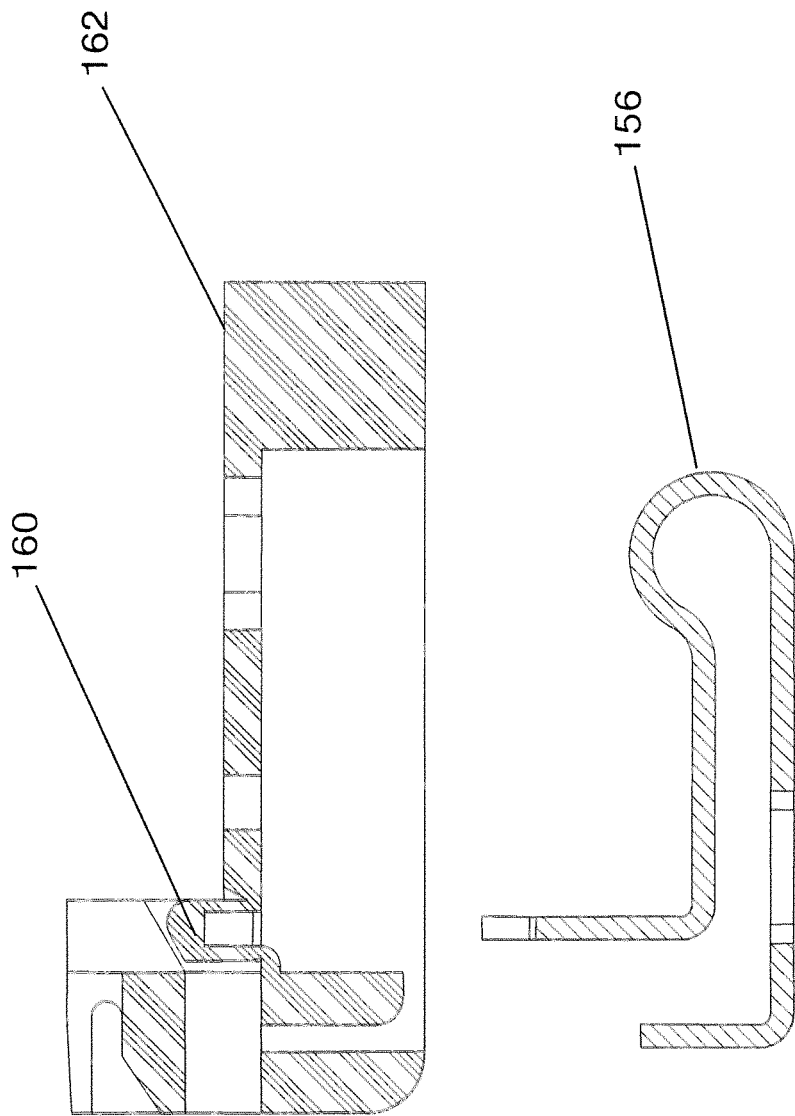


FIG.26

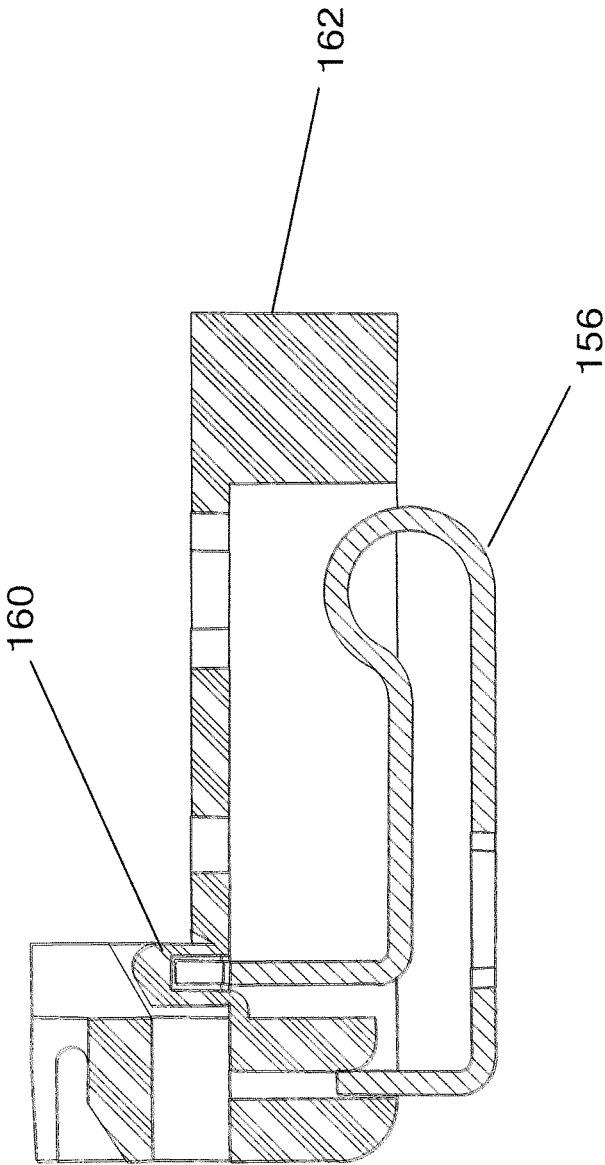


FIG. 27

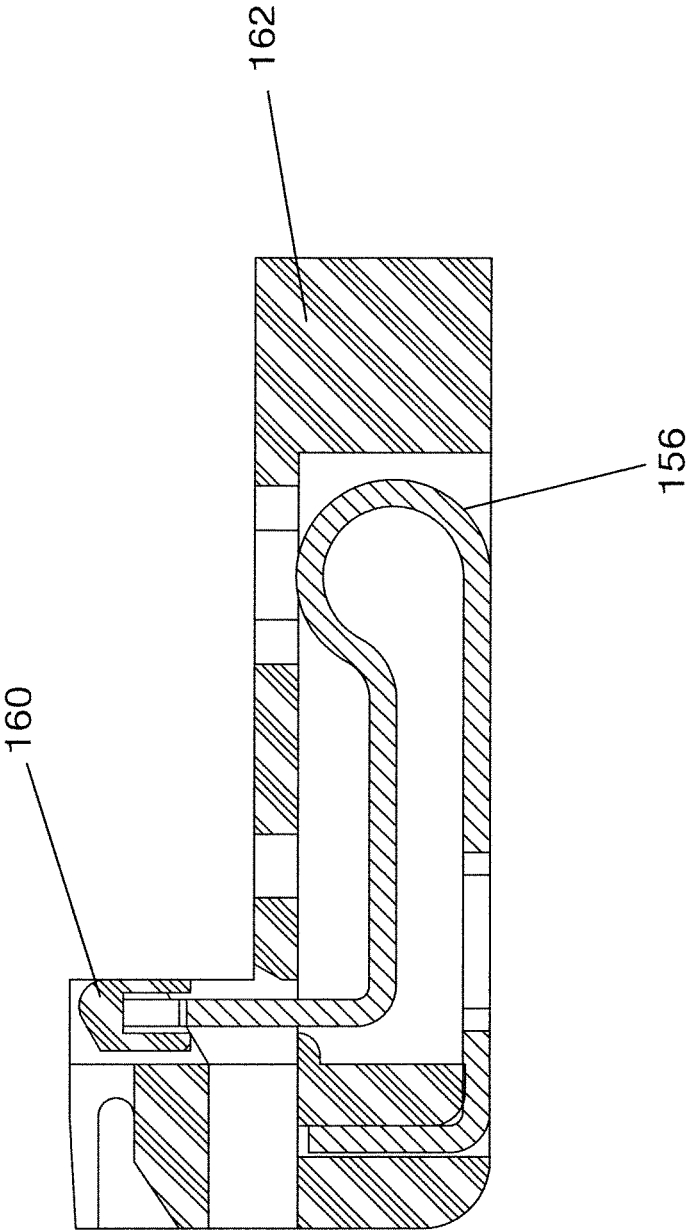


FIG.28

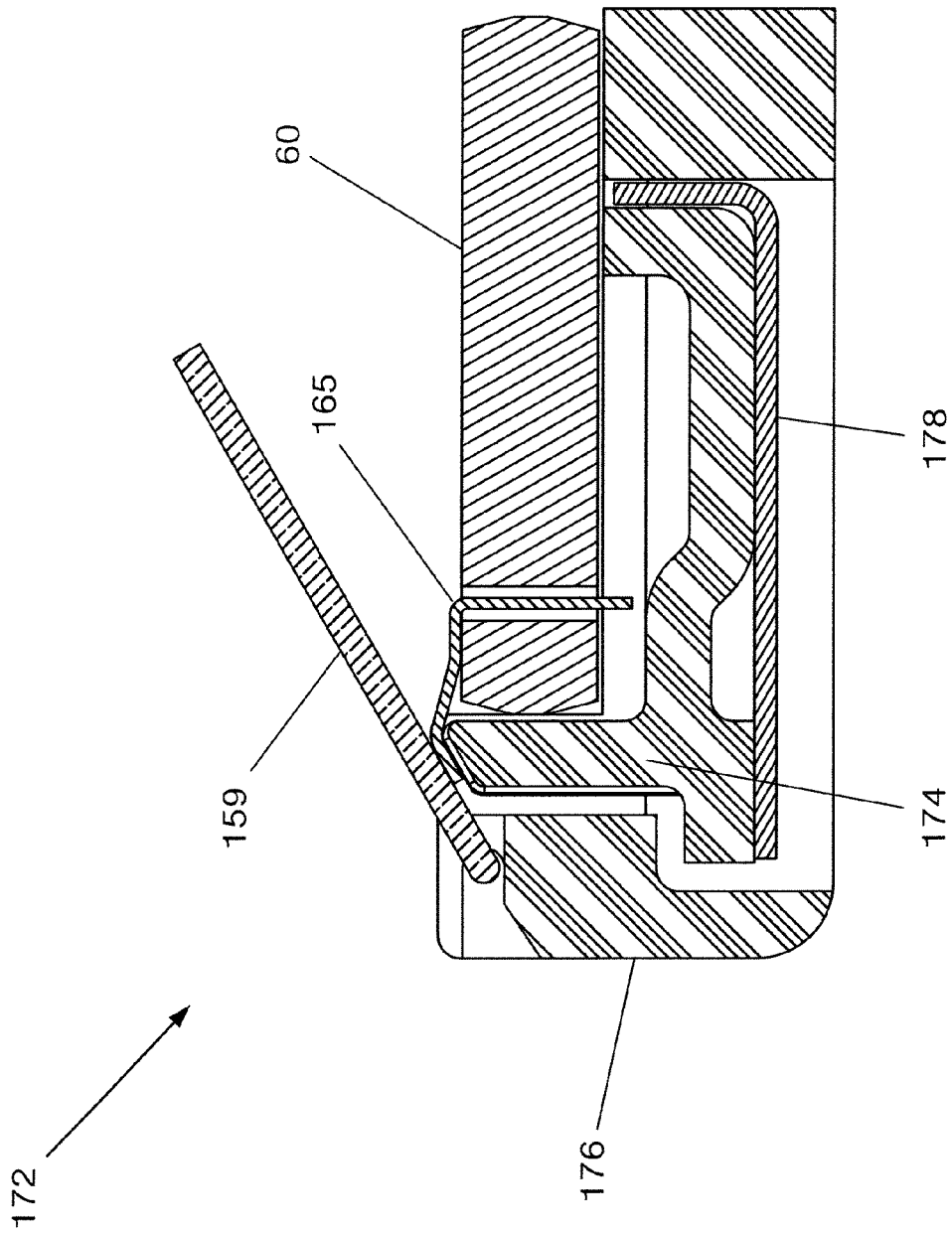


FIG. 29

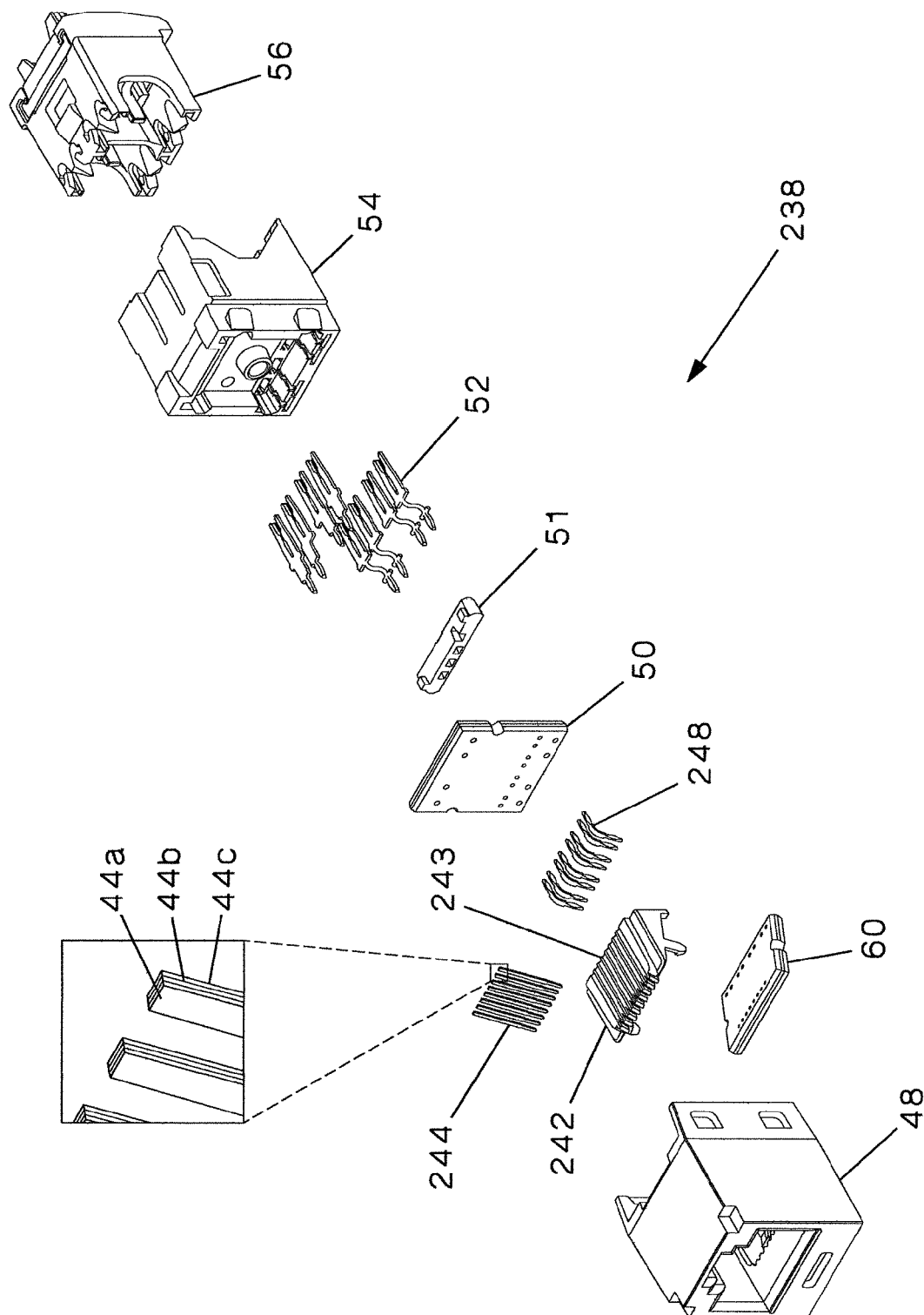


FIG. 30



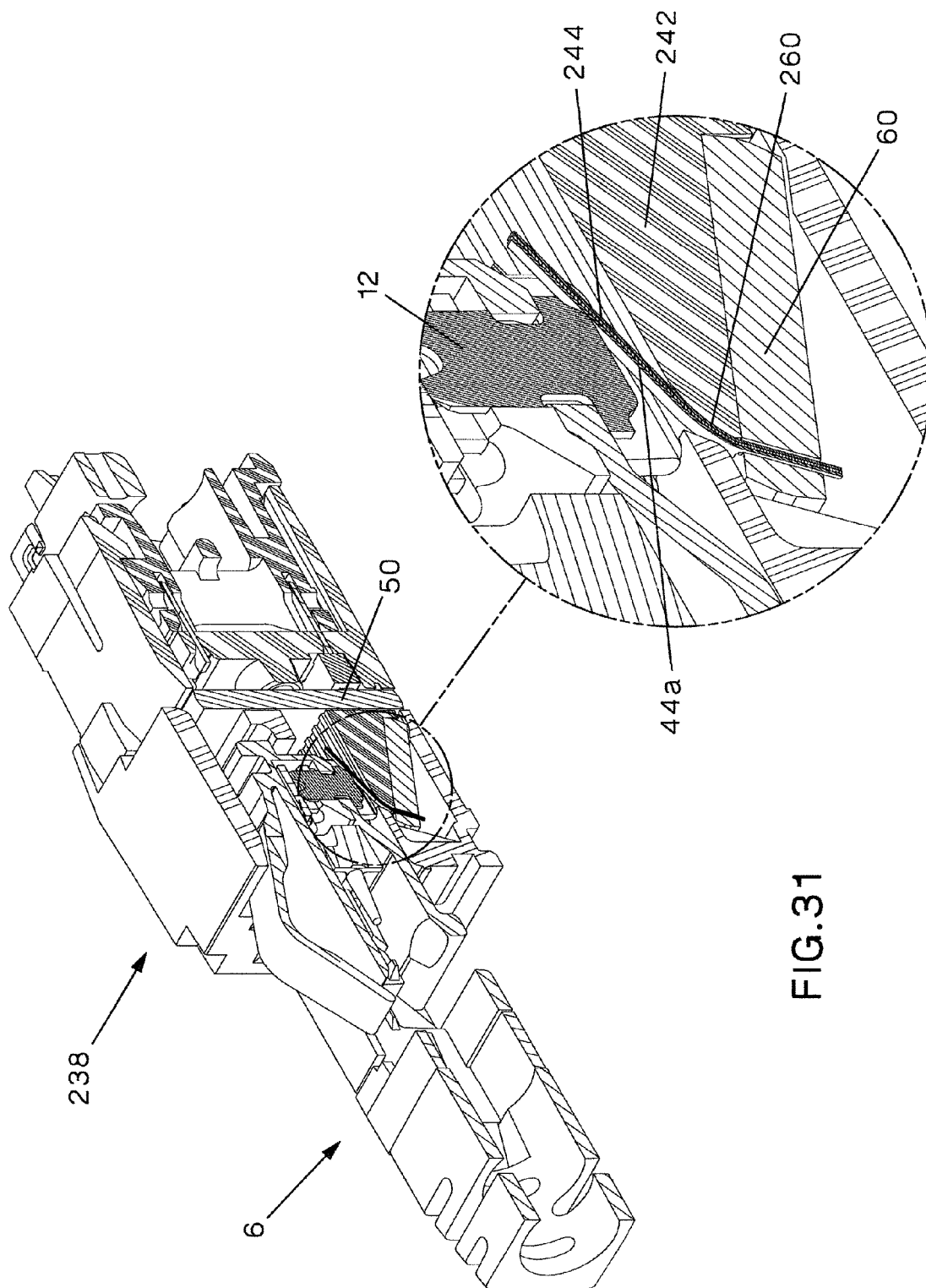


FIG. 31

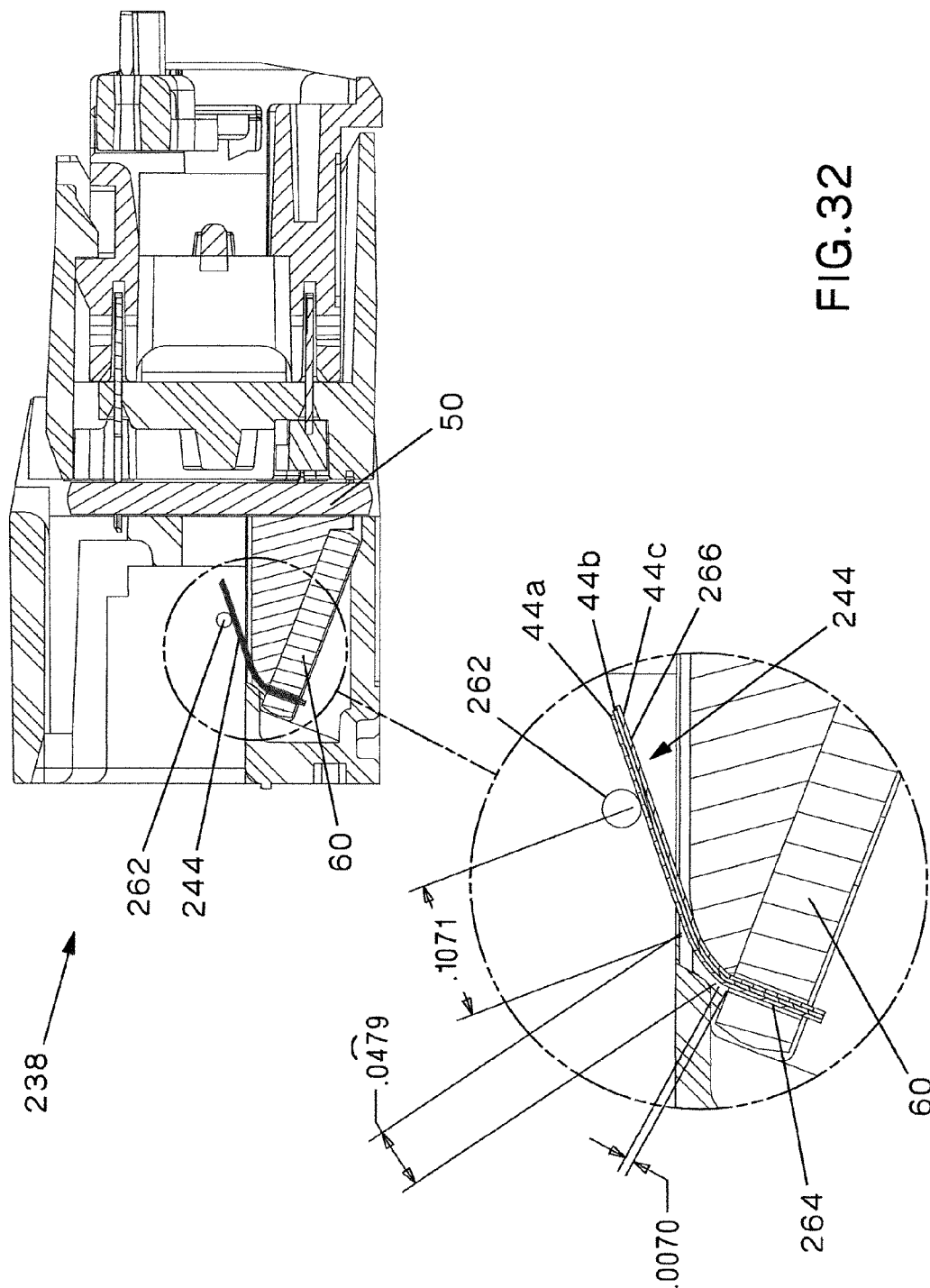


FIG. 32

$$\text{ELECTRICAL LENGTH} = 0.0070'' + 0.0479'' + 0.1071'' = 0.162''$$

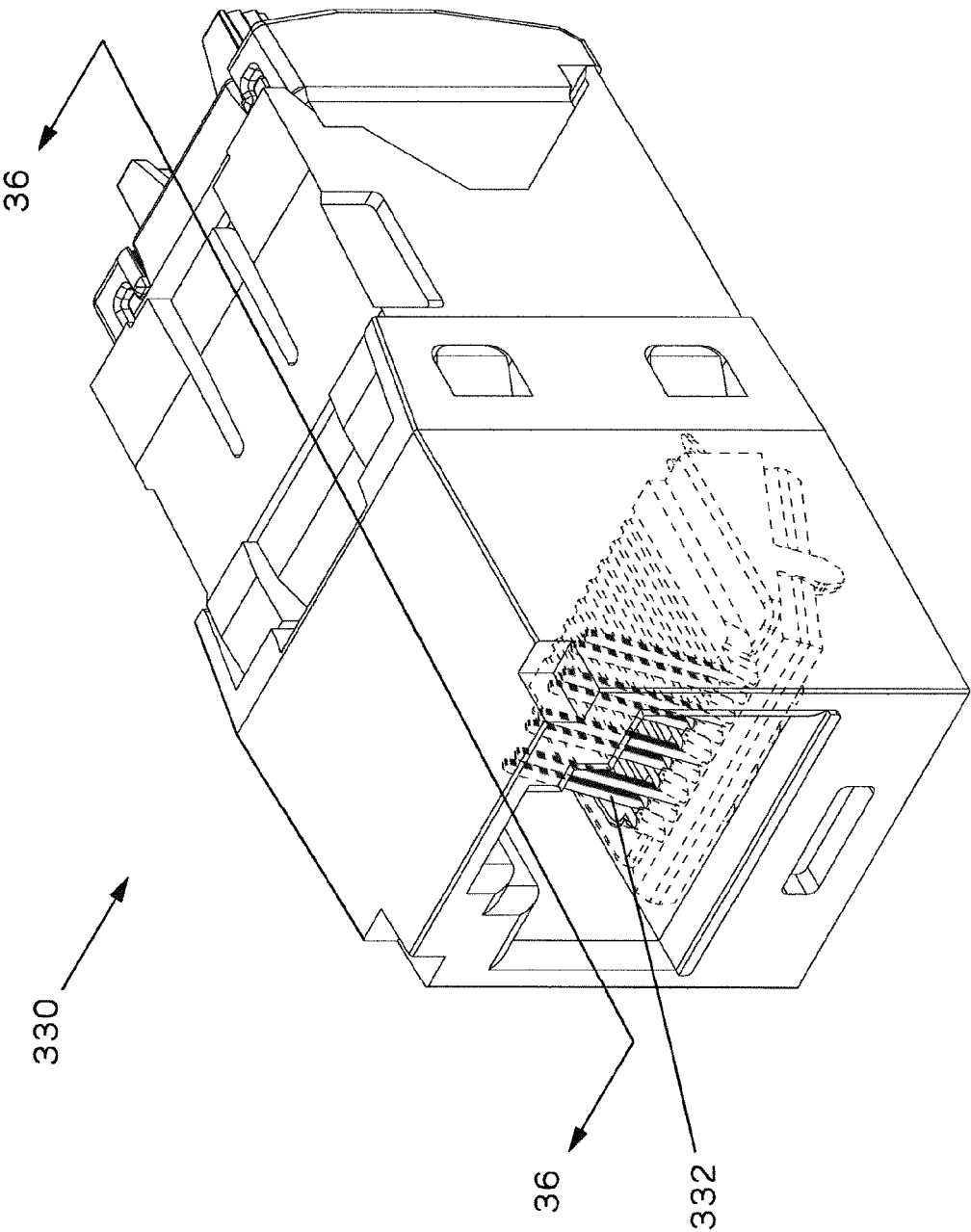


FIG. 33

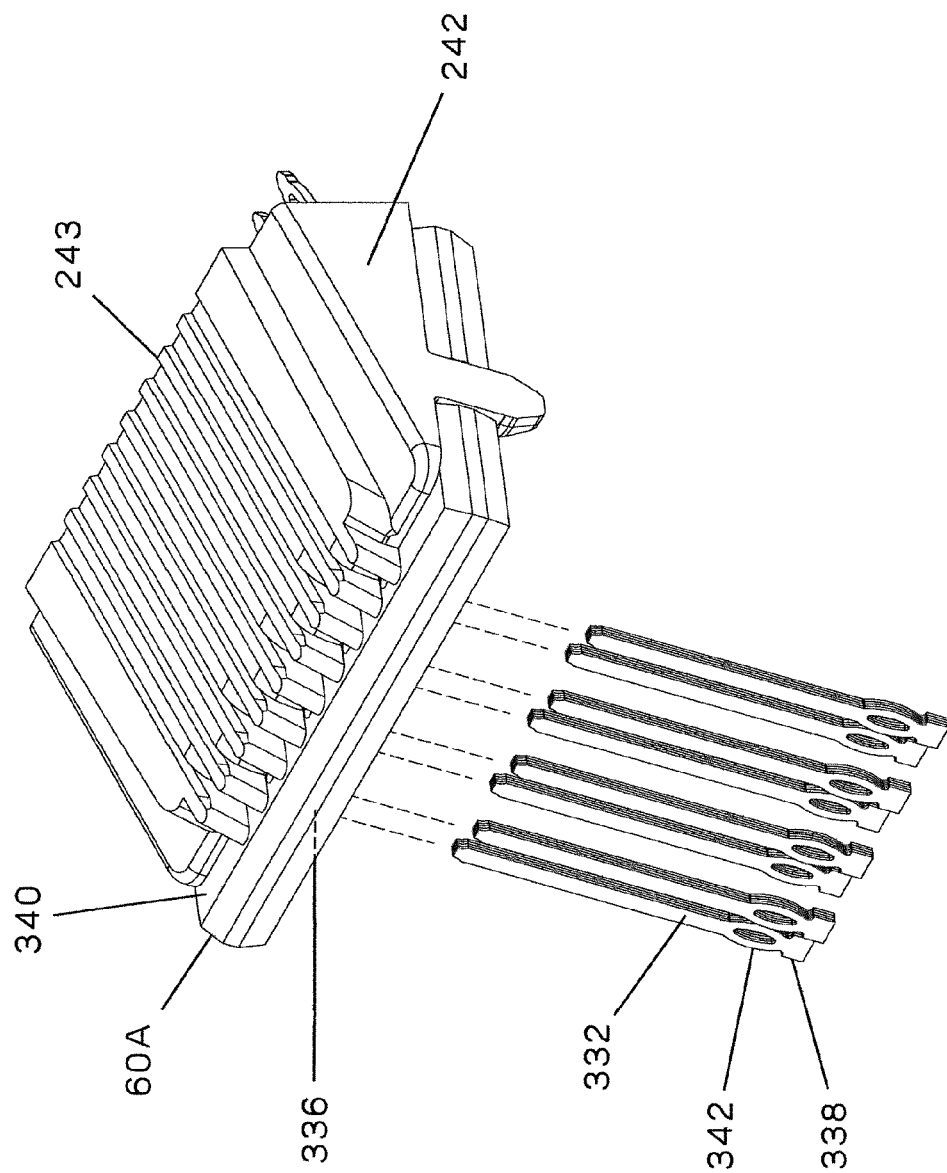


FIG. 34

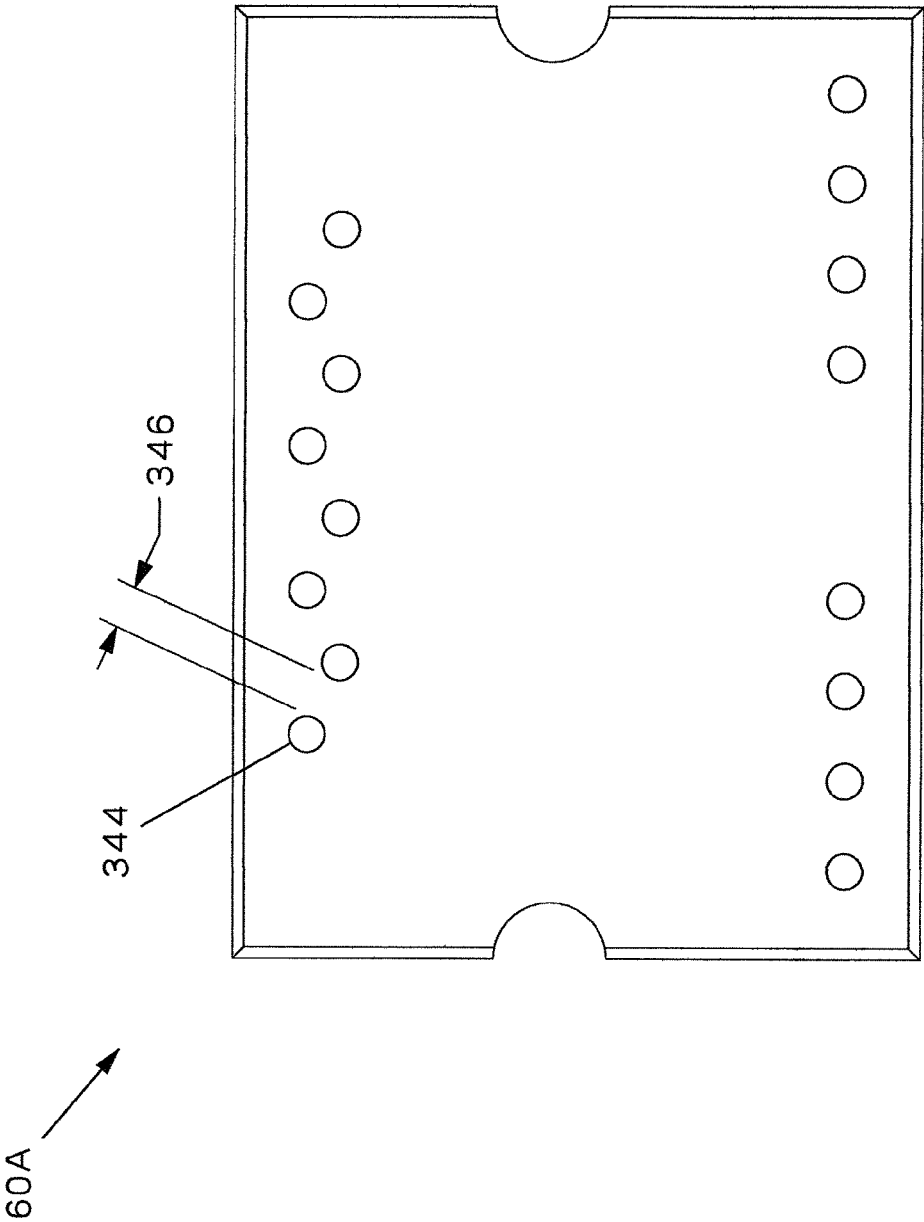
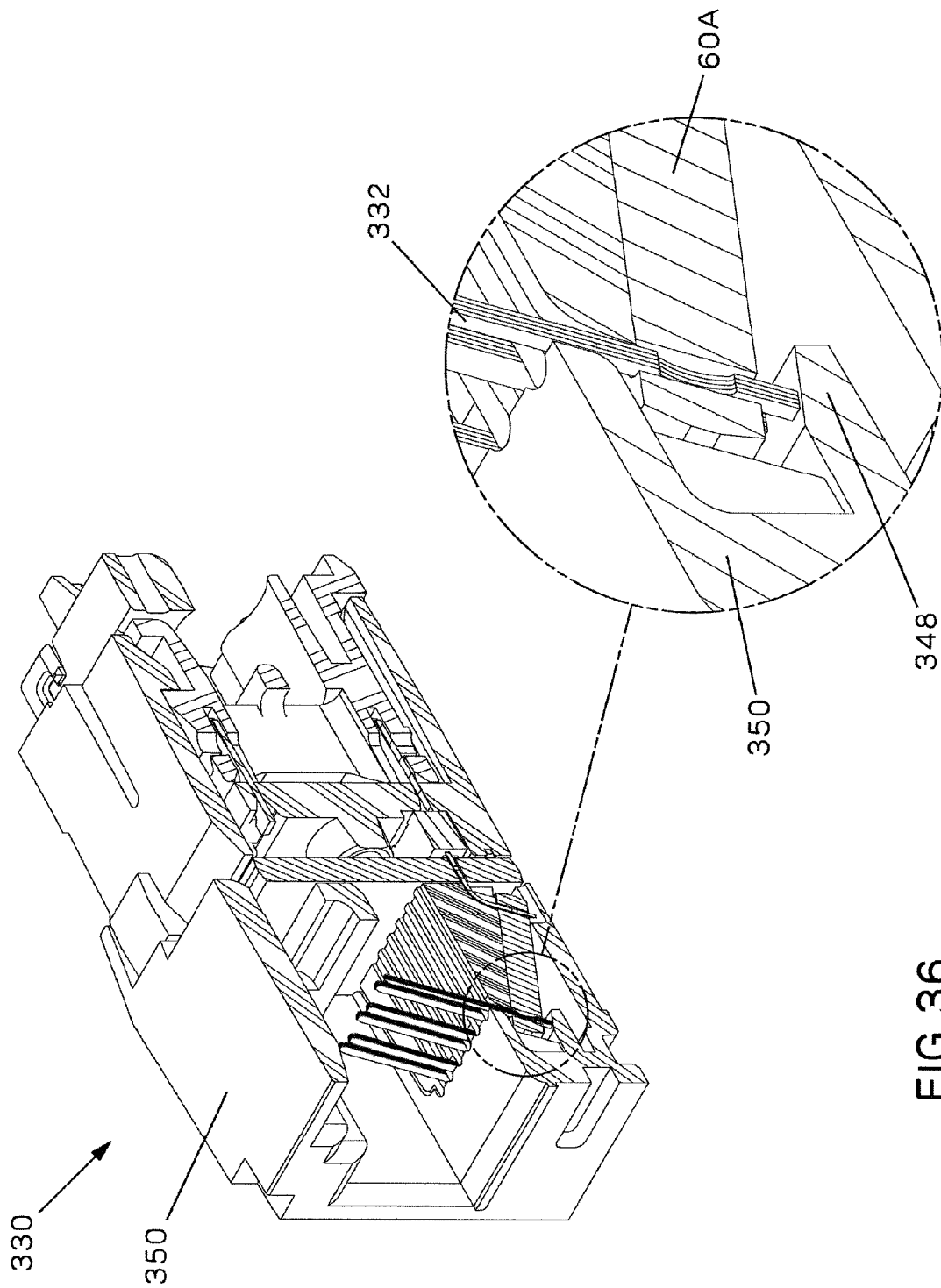


FIG. 35



Soldermask	1.2 mil		
Plated 1 oz copper	2.1 mil	Top Layer	
Prepreg	25 mil		
0.5 oz copper	0.7 mil	Inner Layer 1	Previous 4-layer stack-up. Capacitors are formed between inner layer 1 and 2.
4 mil core	4 mil		
0.5 oz copper	0.7 mil	Inner Layer 2	
Prepreg	25 mil		
Plated 1 oz copper	2.1 mil	Bottom Layer	
Soldermask	1.2 mil		
TOTAL THICKNESS:		62	

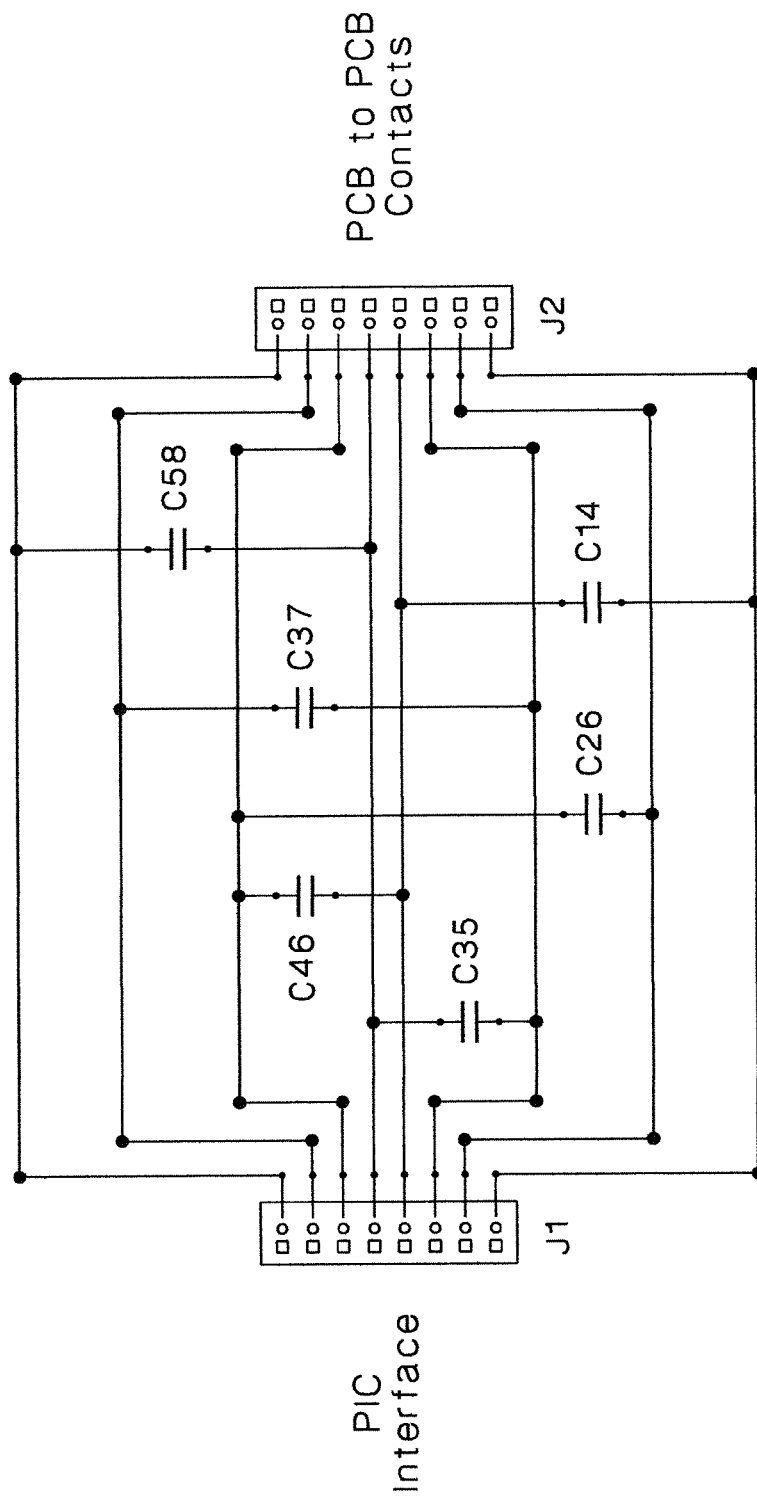
---

Soldermask	1.2 mil		
Plated 1 oz copper	2.1 mil	Top Layer	4-layer stack-up used for horizontal rigid board 60A. Note that now capacitors are formed between the top layer and inner layer 1, in addition to the bottom layer and inner layer 2.
Prepreg	25 mil		
1 oz copper	1.4 mil	Inner Layer 1	
4 mil core	4 mil		
1 oz copper	1.4 mil	Inner Layer 1	
Prepreg	25 mil		
Plated 1 oz copper	2.1 mil	Bottom Layer	
Soldermask	1.2 mil		
TOTAL THICKNESS:		63.4	

---

Soldermask	1.2 mil		
Plated 1 oz copper	2.1 mil	Top Layer	2-layer stack-up used for the vertical board 50A. Since no capacitors are on it, a 2-layer design was used for cost savings.
Core	55.4 mil		
Plated 1 oz copper	2.1 mil	Bottom Layer	
Soldermask	1.2 mil		
TOTAL THICKNESS:		62	

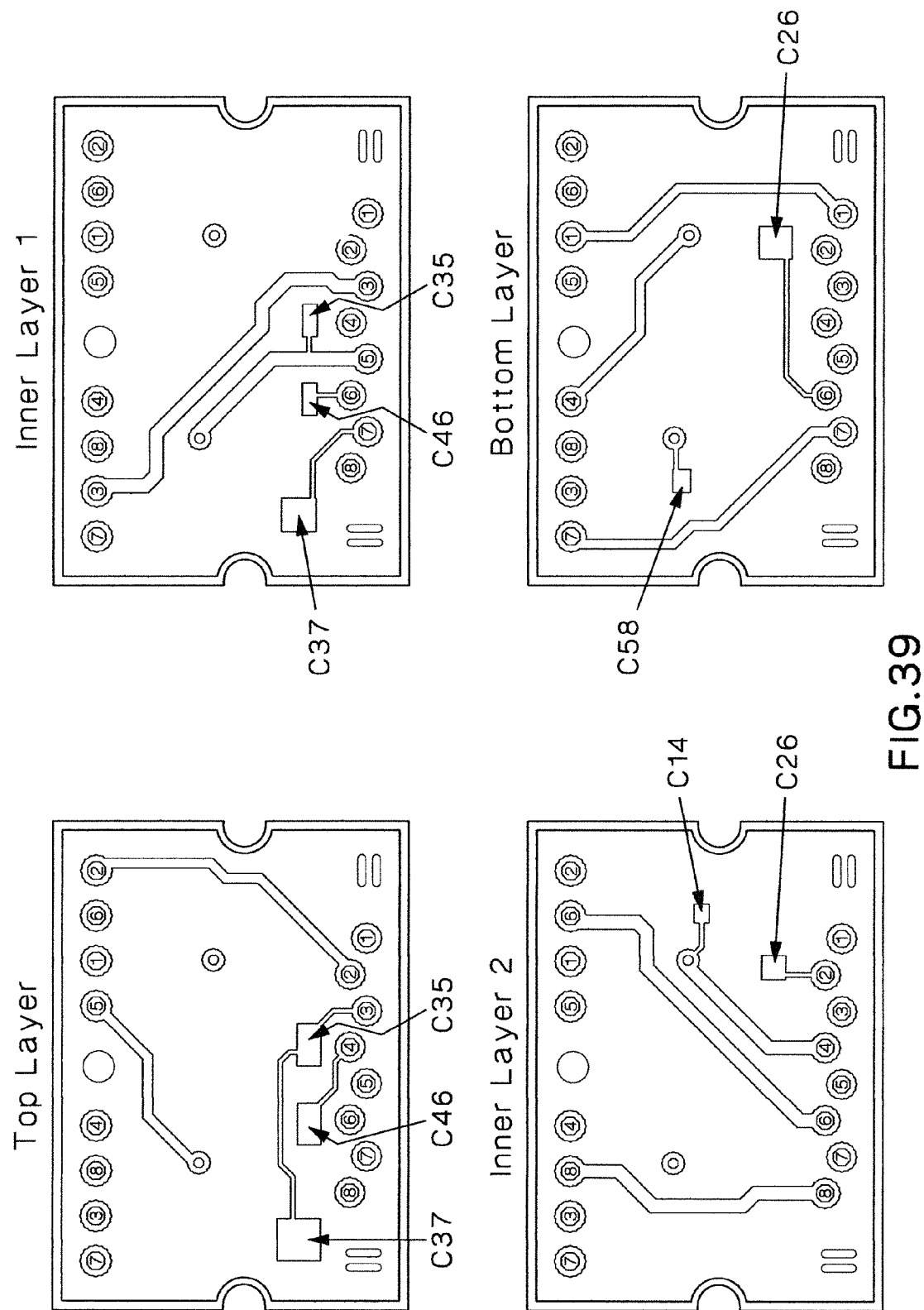
FIG.37



60A

FIG.38





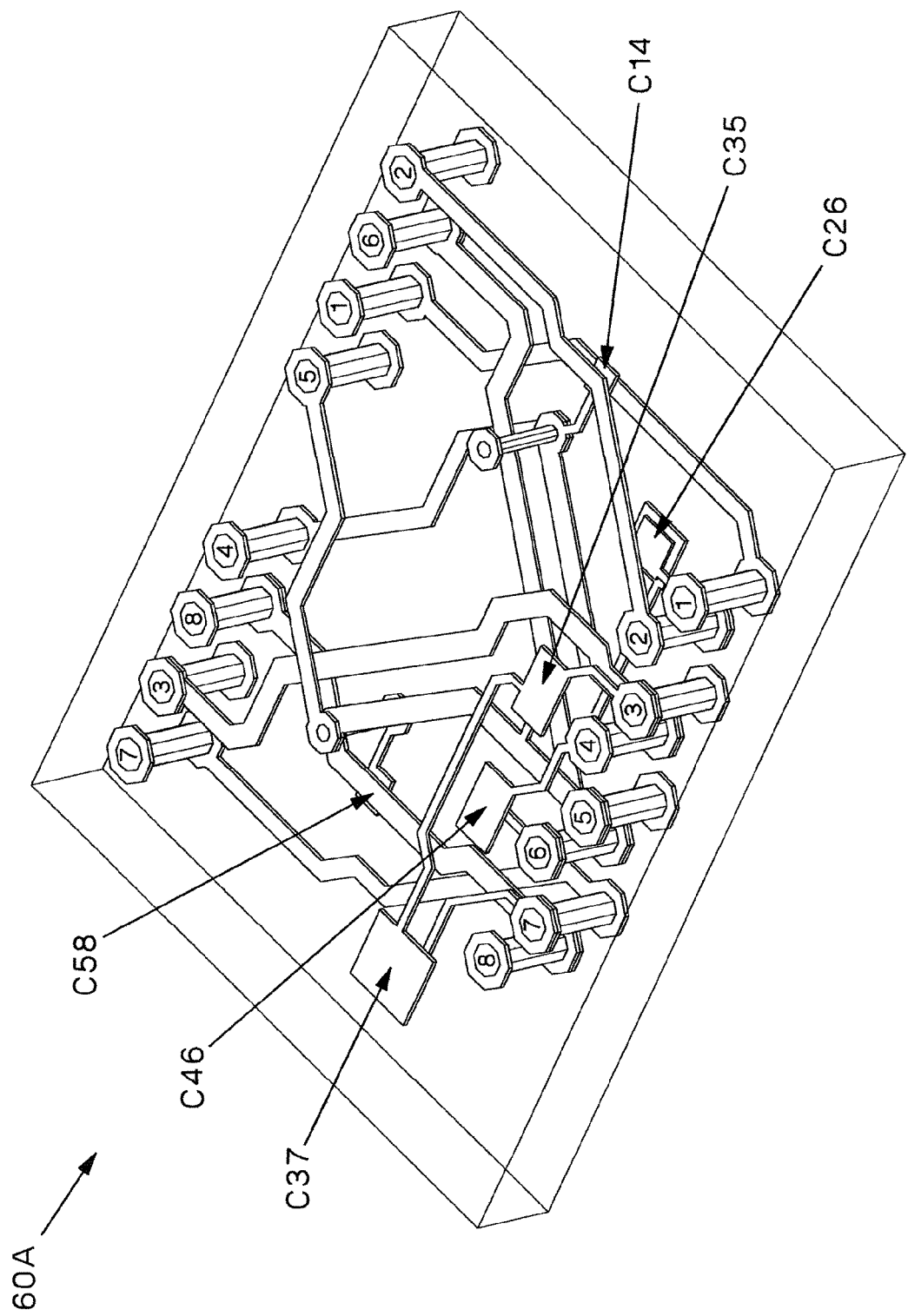


FIG. 40

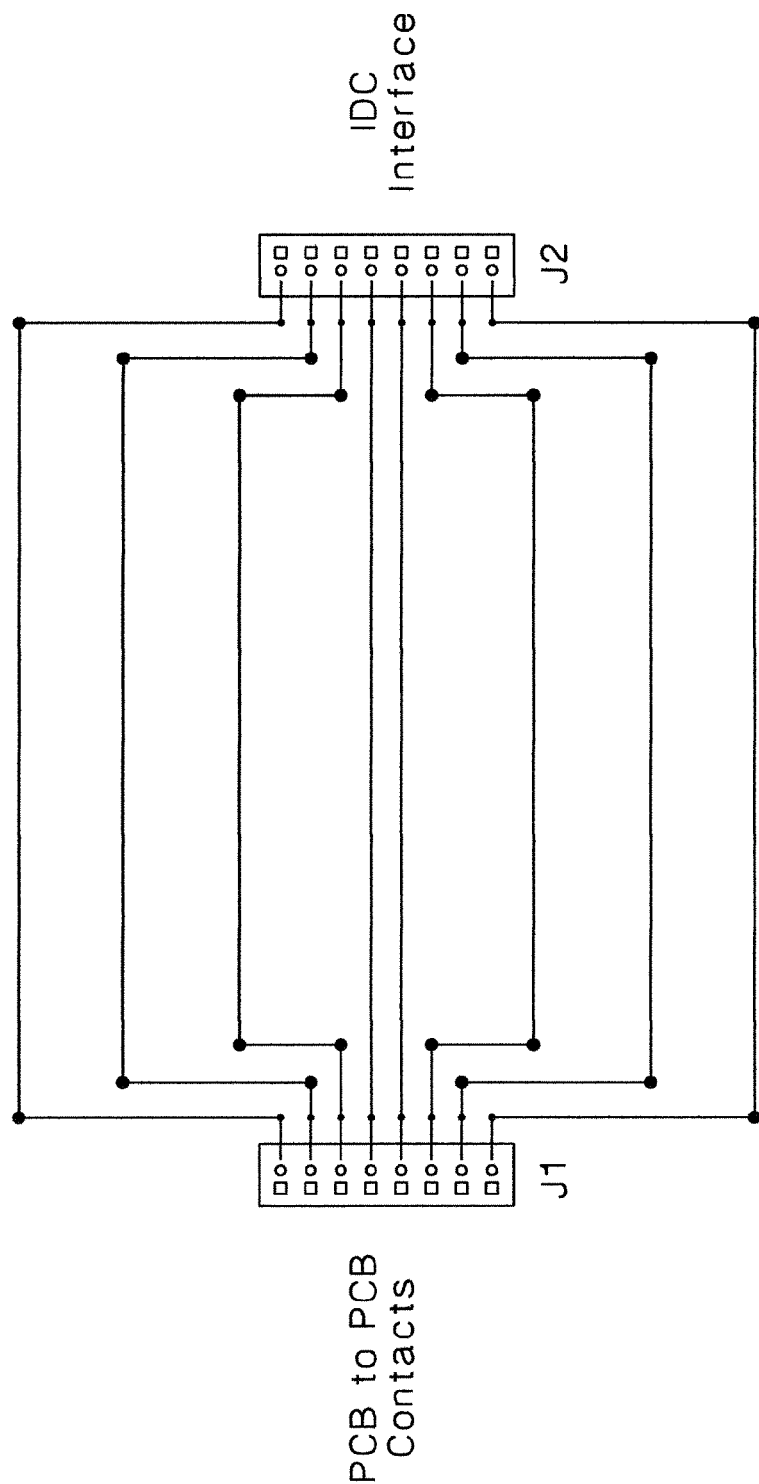


FIG. 41

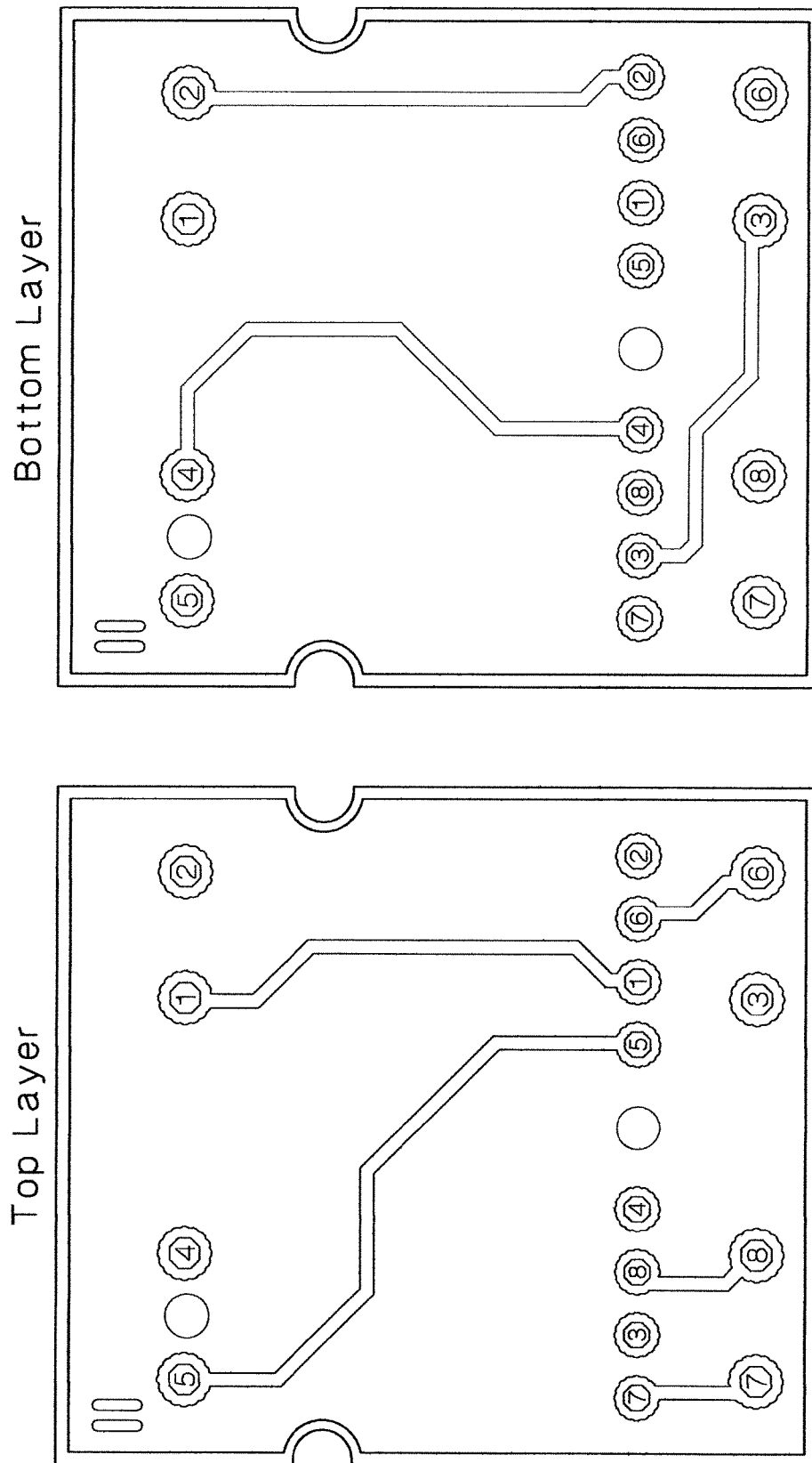


FIG. 42

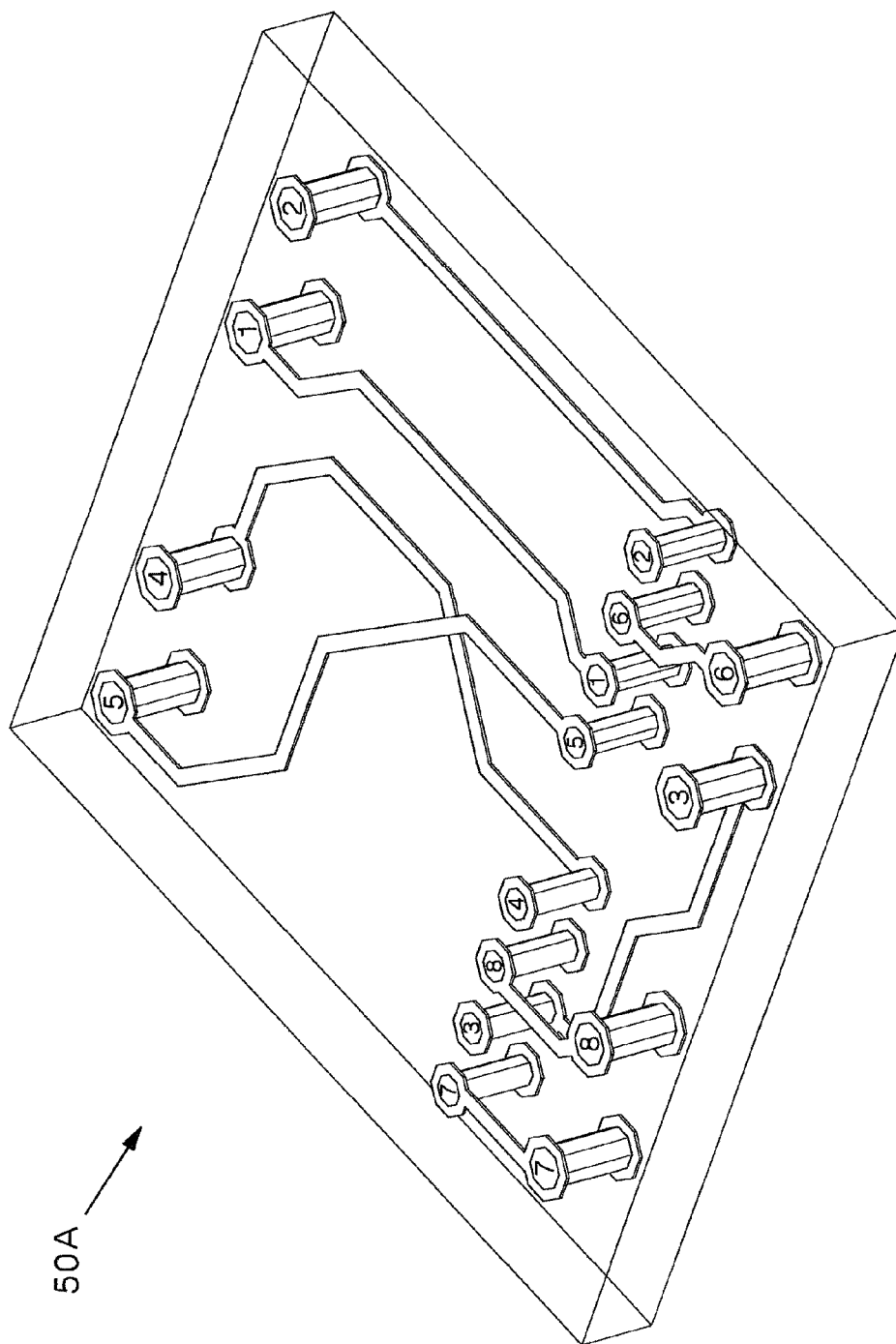


FIG. 43

1

## COMMUNICATION CONNECTOR WITH A PLURALITY OF PLUG INTERFACE CONTACTS

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 13/425,130, filed Mar. 20, 2012, which claims priority to U.S. Provisional Application Ser. No. 61/466,201, filed Mar. 22, 2011, the entire disclosure of which are hereby incorporated by reference.

### FIELD OF THE INVENTION

The present invention relates generally to a communication connector, and more particularly to a communication jack.

### BACKGROUND OF THE INVENTION

In an electrical communication system, it is sometimes advantageous to transmit data in the form of differential signals over a pair of conductive paths (i.e., a conductive path pair) rather than a single conductive path, where the transmitted signal comprises the voltage difference between the conductive paths without regard to the absolute voltages present. Each conductive path in a conductive path pair is capable of picking up electrical noise from outside sources, e.g., neighboring data lines, or other sources. Differential signals may be advantageous to use due to the fact that the signals are less susceptible to these outside sources.

A concern with differential signals is electrical noise that is caused by neighboring differential conductive path pairs, where the individual conductors on each conductive path pair couple (inductively or capacitively) in an unequal manner that results in added noise to the neighboring conductive path pair. This is referred to as crosstalk.

The ability of a data connector to support higher bandwidths depends, at least in part, on the amount of crosstalk that it adds to the system. Ideally, the connector should be transparent to the system, meaning it should not add any crosstalk to the system. For systems using RJ45 style connectors, as are known in the art, crosstalk is inherent to the conductor pair layout. For this type of connector, crosstalk reduction and suppression become critical. Some of the crosstalk reduction efforts focus on isolation, minimizing capacitive and inductive imbalances, and reducing the overall path length of conductors within the connector.

FIGS. 1-3 provide an overview of a known RJ45 style connector. FIG. 1 depicts a connector 2 shown comprising a known communication jack 4 and a communication plug 6 in a connected position, although both communication jack 4 and communication plug 6 can separately each be considered a connector. FIG. 2 depicts the known communication jack 4, which is shown comprising plug interface contacts (PICs) 10, and FIG. 3 depicts the communication plug 6, which is shown comprising plug contacts 12.

RJ45 connector parameters are defined by the ANSI/TIA-568-C.2 standard, and noise suppression typically takes place inside the communication jack 4 of the connector 2. The effectiveness of the suppression depends in part on (i) the distance from the plug contacts 12 on the communication plug 6 and the PICs 10 on the communication jack 4 to the compensation elements in the communication jack 4, and (ii) inductive and capacitive balance.

For interoperability and long term reliability, the communication jack 4 is also required to meet stringent physical and

2

mechanical requirements, such as certain contact angles, normal force, and insertion cycles relative to the PICs 10 on the communication jack 4. Crosstalk suppression favors a shorter contact length, yet the mechanical requirements often require longer contacts than can be readily used for crosstalk suppression. In most cases, the length required to meet the mechanical requirements is a limiting factor. Hence, it becomes beneficial for higher bandwidth connectors to have PICs that meet mechanical requirements while remaining short enough to enable effective crosstalk suppression.

An exploded perspective illustration of one type of communication jack 4 is depicted in FIG. 4. The communication jack 4 is shown comprising a housing 14 that fits an RJ45 communication plug, a nose 16, a rigid printed circuit board (PCB) 18 connected to insulation displacement contacts (IDCs) 20, a rear sled 22 that holds the IDCs 20, and a wire cap 24 that assists wires within cabling to connect to the IDCs 20. The nose 16 may sit within the housing 14 and provides an interface between the plug contacts and the rigid PCB 18. In this respect, as shown, the nose 16 comprises eight PICs 28 that each mate with a respective plug contact on the communication plug (not shown) on a contact surface and with a through hole on the rigid PCB 18 at an end. As shown, the PICs 28 wrap around a mandrel 34 on the nose 16. The PICs 28 may be supported in the nose 16 by a front bottom sled 30 and a front top sled 32, each mechanically coupled to the PICs 28.

The nose 16 may also include a flexible PCB 26 that provides crosstalk compensation when the flexible PCB 26 is in contact with the PICs 28. As shown, the flexible PCB 26 wraps around the same mandrel 34 as the PICs 28, and includes conductive traces on at least one side and/or layer that facilitate electrical contact with the PICs 28.

The interaction of the communication jack 4 and communication plug 6 may be seen in FIG. 5. In the communication jack 4, the PICs 28 operate dually as electrical contacts and mechanical springs. However, as discussed above, the electrical and mechanical functions of the PICs 28 are somewhat opposed. The PICs 28 are designed to maintain a contact normal force of about 100 grams on the plug contacts 12 in the communication plug in the window of movement. However, the mechanical length necessary to achieve this contact normal force may be detrimental to electrical performance due to inductive and capacitive coupling between a given PIC 28 and other PICs 28, as increased PIC length results in increased coupling.

FIG. 5 shows a first contact point 38, marking the contact between the individual plug contacts 12 and the PICs 28, and a second contact point 40, marking the contact between the PICs 28 and the flexible PCB 26. The distance 36 between the first contact point 38 and the second contact point 40 is smaller than on a typical communication jack that does not utilize a flexible PCB 26. The shorter distance 36 increases the effectiveness of crosstalk compensation in the flexible PCB 26.

However, while the communication jack of FIGS. 1-5 provides some improvement in crosstalk suppression, the design also is subject to potential difficulties. First, the flexible PCB 26 costs more than the standard rigid PCB 18. Additionally, due to the small size and low weight of the flexible PCB 26 there can be difficulties in handling during manufacturing.

Thus, manufacture of the circuit board components for communication jack 4 requires two different manufacturing processes for the flexible PCB 26 and the rigid PCB 18. In some cases, these processes can have etching tolerances at opposite ends of the tolerance spectrum. Such mismatch along the tolerance spectrum results in a mismatch in the

3

balancing capacitors located on the flexible PCB 26 and the rigid PCB 18. The unbalanced capacitors will fail to cancel the crosstalk effectively and will yield a connector with poor performance. The limitations and complexity of the manufacture of the communication jack 4 may additionally require that the section of the PICs 28 from the sled mandrel 34 to the rigid PCB 18 be routed in a particular way that may add to coupling within the connector as well as between adjacent connectors. In order to reduce coupled crosstalk between the connectors, spacing must be increased between the connectors, or foil wrap must be added around the connector. The increased spacing reduces the number of connectors in a given space and addition of the foil increases the connector cost.

### SUMMARY OF THE INVENTION

The present invention comprises, in at least one embodiment thereof, a communication jack which includes a housing with an aperture for receiving a communication plug, and a circuit board at least partially within the housing. The circuit board includes crosstalk compensation elements. A plurality of plug interface contacts are connected to the circuit board. At least one of the plurality of plug interface contacts includes a contact element layered with at least one spring element.

The present invention comprises, in another embodiment thereof, a communication system including electrical equipment connected to at least one communication jack. The jack includes a housing with an aperture for receiving a communication plug, and a circuit board at least partially within the housing. The circuit board includes crosstalk compensation elements. A plurality of plug interface contacts are connected to the circuit board. At least one of the plurality of plug interface contacts includes a contact element layered with at least one spring element.

The present invention comprises, in another embodiment thereof, a communication jack for compensating a source of crosstalk in a mated communication plug over a range of signal operating frequencies. The jack includes a plurality of plug interface contacts (PICs), where each PIC comprises a spring element, a contact element pivotally connected to the spring element, and an electrically insulating element, wherein the electrically insulating element connects the contact element to the spring element.

The present invention comprises, in another embodiment thereof, a communication system which includes an electrical equipment and a communication jack connected to the electrical equipment. The jack includes a plurality of plug interface contacts (PICs), where each PIC comprises a spring element, a contact element pivotally connected to the spring element, and an electrically insulating element, wherein the electrically insulating element connects the contact element to the spring element.

The present invention comprises, in another embodiment thereof, a communication jack for compensating a source of crosstalk in a mated communication plug over a range of signal operating frequencies, which includes a plurality of plug interface contacts (PICs). Each PIC has a spring element, an electrically insulating element, and a contact element. The contact element has a free end and a spring end, and the electrically insulating element is connected between the spring element and the spring end of the contact element.

The present invention comprises, in another embodiment thereof, a communication system which includes an electrical equipment and a communication jack connected to the electrical equipment. The jack includes a plurality of plug interface contacts (PICs). Each PIC has a spring element, an

4

electrically insulating element, and a contact element. The contact element has a free end and a spring end, and the electrically insulating element is connected between the spring element and the spring end of the contact element.

The present invention comprises, in another embodiment thereof, a method of manufacturing a communication jack for compensating a source of crosstalk in a mated communication plug over a range of signal operating frequencies. The method includes the steps of providing a printed circuit board comprising one or more crosstalk compensation circuits; and contacting a plug interface contact (PIC) to a contact on the printed circuit board, wherein the PIC comprises: a spring element, a contact element pivotally connected to the spring element, and an electrically insulating element, wherein the electrically insulating element connects the contact element to the spring element.

The present invention comprises, in another embodiment thereof, a communication jack, which includes at least one printed circuit board having a plurality of conductors arranged in respective signal pairs, wherein the at least one printed circuit board is subjected to a manufacturing variation. A first stage of at least one first capacitor is connected between one of the plurality of conductors for a first signal pair of the signal pairs and another of the plurality of conductors for a second signal pair of the signal pairs. A second stage includes at least one second capacitor of an opposite polarity of the first capacitor(s), where the second capacitor(s) is/are connected between the first signal pair and the second signal pair. At least one second capacitor includes a geometry that is chosen such that a net capacitance of the first stage and the second stage is minimized in the presence of the manufacturing variation.

The present invention comprises, in another embodiment thereof, a method of designing a communication jack. The method comprises the steps of: providing a circuit board at least partially within a jack housing and having a first stage of capacitors and a second stage of capacitors for at least partially improving an electrical performance of the jack; optimizing the first stage of capacitors and the second stage of capacitors for the electrical performance; and compensating for the effect of a manufacturing variation of the circuit board to minimize the effect of the manufacturing variation on the electrical performance.

An advantage of at least one embodiment of the present invention is a communication jack with a shorter electrical length between the point of contact with mating plug contacts and the first compensation stage in the jack.

Another advantage of at least one embodiment of the present invention is a communication jack with shorter PIC lengths thereby reducing the jack susceptibility to crosstalk.

Yet another advantage of at least one embodiment of the present invention is a communication jack that has improved electrical performance and is relatively cost effective to manufacture.

Yet another advantage of at least one embodiment of the present invention is a communication jack that reduces the effect of manufacturing variation on electrical performance.

### BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

5

FIG. 1 is a perspective view of a communication connector including a communication jack with a mated communication plug;

FIG. 2 is a perspective view of the communication jack of FIG. 1;

FIG. 3 is a perspective view of the communication plug of FIG. 1;

FIG. 4 is an exploded perspective view of the communication Jack of FIGS. 1 and 2;

FIG. 5 is a cross-sectional view of the communication connector of FIG. 1 taken along section line 5-5;

FIG. 6 is a perspective view of a communication jack in accordance with an embodiment of the present invention;

FIG. 7 is an exploded perspective view of the communication jack of FIG. 6;

FIG. 8 is a perspective view of the front sled assembly of the jack of FIG. 6;

FIG. 9 is a fragmentary perspective view of the front sled assembly of the jack of FIG. 8;

FIG. 10 is a cross-sectional view of the communication jack of FIG. 6 with a mated communication plug in accordance with an embodiment of the present invention;

FIG. 11 is a more detailed perspective view of the front sled assembly of FIG. 8;

FIG. 12 is a partial front view of the front sled assembly of FIG. 11;

FIGS. 13A-17 are various views of an embodiment of two rigid PCBs which can be used in a communication jack according to the present invention;

FIG. 18 is a cross-sectional perspective view of another communication jack with a mated communication plug in accordance with an embodiment of the present invention;

FIG. 19 is a fragmentary perspective view of a communication system according to the present invention;

FIGS. 20-29 are various views of another embodiment of a communication jack according to the present invention;

FIGS. 30-32 are various views of another embodiment of a communication jack according to the present invention;

FIGS. 33-36 are various views of another embodiment of a communication jack according to the present invention;

FIGS. 37-43 are various views of another embodiment of two rigid PCBs which can be used in a communication jack according to the present invention

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates preferred embodiments of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

#### DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

FIG. 6 depicts a communication jack in accordance with an embodiment of the present invention. The communication jack 44 can include PICs. The PICs are made up of contact elements 46, electrically insulating elements 62, and mechanical spring elements 64 as shown in FIG. 7. Each of the elements will be described in further detail below. As described above with respect to background embodiments, the PICs serve to mate with plug contacts on a communication plug (not shown). In particular, the contact elements 46 of the PICs serve to mate with the plug contacts.

An exploded perspective illustration of the communication jack 44 is shown in FIG. 7. The communication jack 44 is shown comprising a housing 48, a vertical rigid PCB 50, insulation displacement contacts (IDCs) 52, a rear sled 54, a wire cap 56, and the PICs. The contact elements 46 of the

6

PICs are operable to contact with respective plug contacts (not shown) as well as with a horizontal rigid PCB 60 by way of through contacts 58. The through contacts 58 are made of a conductive material, such as a copper alloy. While the communication jack 44 is shown comprising eight PICs, more or fewer PICs are possible.

As described above, PICs in the communication jack 44 have both an electrical function and a mechanical function. The PICs optimize electrical functionality through the design of the contact elements 46. The contact elements 46 have shorter lengths relative to the PICs of typical communication jacks as described above. The shorter lengths of the contact elements 46 result in reduced coupling between the contacts, as described above.

However, for the illustrated example, the PICs must also provide a requisite contact normal force of about 100 grams on the plug contacts in the window of movement. The contact normal force is necessary to have a low-resistance interface for the communication plug. The PICs have improved mechanical functionality through the design of the mechanical spring elements 64. The mechanical spring elements 64 provide the communication jack 44 the requisite contact normal force between the PICs and the contacts of the plug 12.

The tradeoff between the electrical and mechanical functionalities of the PICs is addressed through the use of the electrically insulating elements 62. The electrically insulating elements 62 connect the contact elements 46 to the mechanical spring elements 64. In this manner, the contact elements 46 are electrically insulated from the mechanical spring elements 64, meaning the mechanical spring elements 64 do not extend the electrical length of the PICs. Rather, only the contact elements 46 of the PICs operate as part of the electrical circuit in the communication jack 44. Thus, the communication jack 44 reduces crosstalk at the contacts while still providing the requisite contact normal force.

As mentioned above, the contact elements 46 of each PIC are connected to the mechanical spring elements 64 via the electrically insulating elements 62. In some embodiments, the contact elements may be pivotally connected to the mechanical spring elements 64. Thus, the spring elements 64 may be made of a conductive material but still will not extend the electrical length of the PIC. Alternatively, the spring elements 64 may be made of a non-conductive material such that the electrically insulating elements 62 may be omitted.

FIGS. 8 and 9 depict portions of a communication jack in accordance with an embodiment of the present invention and are included to assist in illustrating the mechanical functionality of the communication jack 44. As shown in FIG. 8, the contact elements 46 of the PICs are each respectively connected to the mechanical spring elements 64 via the electrically insulating elements 62 and are supported by front sled 66. As a communication plug (not shown) is inserted into the communication jack 44, the contact elements 46 will act as levers, rotating around the front edge of the horizontal rigid PCB 60. The contact elements 46 will wipe with respective through contacts 58, establishing electrical connection with the horizontal rigid PCB 60. Additionally, the lever-like motion of the contact elements 46 will lift respective mechanical spring elements 64. The resistance of the mechanical spring elements 64 to the upward motion provides the contact normal force at the interface between the contact elements 46 and the plug contacts.

FIG. 9 is similar to FIG. 8, except that only one set of a contact element 46, electrically insulating element 62, and a mechanical spring element 84 is shown. FIG. 9 makes it easy to see how the lever-like motion of the contact element 46 would cause an upward force on the mechanical spring ele-



7

ment 64. It can also be seen from FIG. 9 how the electrical length of the PIC is limited to the relatively short length of the contact element through the use of the electrically insulating element 62 to connect the contact element 46 and the mechanical spring element 64.

The contact elements 46 may be manufactured using non-spring materials. As the mechanical spring elements 64 are electrically isolated from the contact elements 46, the mechanical spring elements 64 may be made longer to withstand the displacement of the contact elements 46 over a range of plug-contact crimp heights, including four- and six-position plug insertion. As a result of the electrically insulating elements 62, such an increase in the length of the mechanical spring elements 64 does not increase the electrical length of the PIC as a whole. This electrical isolation further essentially eliminates inductive and capacitive coupling between the mechanical spring elements 64 themselves.

Referring to the more detailed view of FIGS. 11 and 12, PICs 22 are electrically connected to PCB 60 through wiping contacts 24; see particularly upright arms 25 of contacts 24 shown particularly in FIG. 3. Wiping contacts 24 must be relatively thin so as to not disrupt the PICs' 22 ability to rotate freely.

In some embodiments, there may be eight PICs in the communication jack, as shown. Each of the PICs is identical and is formed in the same manner as the rest. As such, fabrication may be simplified. For example, the PICs may be stamped on one strip at 0.04 inches centerline. The shorter length of the PICs reduces the requisite strip width, and thus, overall material costs.

The mechanical spring elements 64 are similar to one another. The mechanical spring elements 64 may be made from plastic resin or ferrous metal, or other metal, to help lower costs.

FIG. 10 is a fragmentary perspective view of a communication jack with a mated communication plug in accordance with a first embodiment of the present invention. The communication jack is shown comprising, among other things, a housing 48 into which the communication plug 6 enters, the horizontal rigid PCB 60, the vertical rigid PCB 50, and a rear sled 54. A portion of the communication jack is expanded to illustrate the electrical and mechanical components and functionalities of the communication jack.

In the expanded view, a plug contact 12 of the entering communication plug 6 is shown making contact with a contact element 46 of a PIC in the communication Jack. The contact element 46 is connected to an electrically insulating element 62 of the PIC that is in turn connected to a spring element 64 of the PIC. The contact element 46 may be described as having a free end 74 and a spring end 76. The electrically insulating element 62 is then connected between the spring element 64 and the spring end 76 of the contact element 46.

As the communication plug 6 enters, the plug contact 12 contacts the contact element 46 and forces the free end 74 of contact element 46 to rotate downwards like a lever. The spring end 76 of the contact element 46 contacts the horizontal rigid PCB 60 and in turn lifts up the insulating element 62, forcing the mechanical spring element 64 to move upward. The spring element 64 resists the upward motion, resulting in a contact normal force on the plug contacts 12. Thus, the mechanical integrity of the communication jack is enabled through the use of spring element 64.

Further, it can be seen from the expanded view that the electrical length of the PIC includes only the length of the contact element 46. Thus, the electrical length can be understood as the distance 72 between the free end 74 of the contact

8

element 46 and the spring end 76 of the contact element 46. In some embodiments, this distance may be around 0.115 inches, and more particularly can be less than 0.160 inches. As described above, this design of the communication jack allows for reducing a source of crosstalk in a mated communication plug over a range of signal operating frequencies.

The horizontal rigid PCB 60 is designed to have the same thickness and core construction of the vertical rigid PCB 50. In this manner, the rigid PCBs may be fabricated together and may have compensating capacitors that change in the same manner. This helps improve production yield and allows the use of rigid PCBs, which reduces cost as compared to the flexible PCBs as used in other solutions. The horizontal rigid PCB 60 is connected to the vertical rigid PCB via right angle contacts 68 (shown in FIG. 7). The right angle contacts 68 may be grouped in pairs and located on the top or bottom of the horizontal rigid PCB 60 to help minimize crosstalk. In some embodiments, the horizontal rigid PCB 60 contacts each PIC at the Interface of a contact element 46 and an electrically insulating element 62. The horizontal rigid PCB 60 may include one or more crosstalk compensation circuits.

Compensation circuits used in embodiments of the present invention may contain capacitors whose size and shape are designed such that when they are subjected to variation in manufacturing from such sources as etching, the net effect on the electrical performance of the jack is minimized. The capacitors are labeled in the drawings according to the conductive traces to which they are connected. Thus, C46 is a capacitor between the 4<sup>th</sup> and 6<sup>th</sup> conductive trace.

As is known in the art of PCB manufacturing, the etching of a PCB starts with a substrate with copper cladding, then a coating of etch resist is applied. Using the PCB artwork, the desired PCB pattern is imaged and developed, the PCB is then placed into a chemical bath for a specified period of time where the unwanted copper cladding is etched away, and the etch resist is stripped away leaving the final PCB artwork. Variations in any part of the process can create variations in the compensation capacitors. Examples of variation can be variation of the chemical composition of the chemical bath as a function of position within the bath, or exposure time variation of the PCB panel within the chemical bath, or copper cladding thickness variation. FIGS. 13A-13B show the layout of PCBs 60 and 50, and FIG. 14 illustrates how PCBs 60 and 50 can be manufactured side by side in a single panel so that they are subject to a similar manufacturing variation. Typically, multiples of the combined PCBs 60 and 50 are configured in a single PCB panel and etched together. FIG. 15 shows their respective schematics. This reduction in manufacturing variation is done by using a technique where the larger compensating capacitors are made square (C35, C46, C13, C68, C58, C47, and C25), and the smaller crosstalk capacitors (C34, C56, C16, C15) are made following the rules of scenarios 1 to 4 explained below.

More specifically, for pair combination 45-36 (C35, C46, C34, C56) a design criteria referred to as scenario 2 is used; for pair combination 36-12 (C13, C16) the scenario 1 design criteria is used; for pair combination 45-12 (C25, C15) the scenario 1 design criteria is used; for pair combination 36-78 C68 is a square in a single first stage; for pair combination 45-78 both C58 and C47 are square in a single first stage; and for pair combination 12-78 no compensation is needed.

To understand these scenarios, one must first understand that in many CAT6 and CAT6A jacks, a two stage compensation scheme is typically used where the first stage uses a capacitor of opposite polarity to the incident crosstalk caused by the plug, and the second stage uses a capacitor of the same polarity as the incident crosstalk caused by the plug. The first

stage capacitor is typically larger than the second stage capacitor. The formula for capacitance between two plates is generally understood by the equation

$$C = \epsilon_r \epsilon_0 A / d, \quad (1)$$

where C is the capacitance in farads (F),  $\epsilon_r$  is the relative dielectric constant of the material between the plates (typically about 4.4 when using FR4),  $\epsilon_0$  is permittivity of free space ( $8.85 \times 10^{-12}$  F/m), A is the area of overlap of the two plates in square meters, and d is the distance between the two plates in meters.

Thus, the net crosstalk on the jack used to cancel the crosstalk caused by the plug is approximately the difference between the two capacitors in the first and second stages (neglecting other parasitic crosstalk elements elsewhere in the jack, mutual inductive coupling, and the frequency dependency of the coupling). This can be written as

$$C_{\text{net}} = C_{\text{stage1}} - C_{\text{stage2}}, \quad (2)$$

where  $C_{\text{net}}$  is the net capacitance.  $C_{\text{stage1}}$  is the capacitance in stage 1, and  $C_{\text{stage2}}$  is the capacitance in stage 2. Equation 1 shows that capacitance is proportional to area. Therefore, if one assumes that both capacitors are created on the same circuit board panel (thus the same etching, dielectric material, and separation),

$$C_{\text{net}} \sim A_{\text{stage1}} - A_{\text{stage2}}, \quad (3)$$

which states that the net capacitance is proportional to the difference in the area of overlap of the plate capacitors comprising stage 1 and stage 2 ( $A_{\text{stage1}}$  and  $A_{\text{stage2}}$ , respectively).

Since the capacitors for stage 1 and stage 2 are made on the same panel, any over-etching or under-etching is assumed to affect both capacitors equally. Therefore, the change in net capacitance for a circuit board that is over-etched or under-etched is given by

$$\Delta C_{\text{net}} \sim \Delta A_{\text{stage1}} - \Delta A_{\text{stage2}}, \quad (4)$$

where  $\Delta C_{\text{net}}$  refers to the change in net capacitance, and  $\Delta A_{\text{stage1}}$  and  $\Delta A_{\text{stage2}}$  both refer to the change in area for stage 1 and stage 2, respectively. By selectively choosing the dimensions of the capacitors comprising stage 1 and stage 2, the overall  $\Delta C_{\text{net}}$  can be minimized for different types of etching variation.

#### Four Scenarios

In general, there are four scenarios that must be examined. For reference, a jack using 2 stages of compensation can have a variety of methods of doing this compensation. Assuming all compensating crosstalk (of opposite polarity of the incident crosstalk caused by the plug) is located in stage 1, and all intentional crosstalk (of the same polarity as the incident crosstalk caused by the plug) is located in stage 2, there are four unique scenarios that should be examined because for a given pair combination, there are four coupling mechanisms. For example, pair combination 45-36 can have coupling between 3-4 and 5-6 (crosstalk) and coupling between 4-6 and 3-5 (compensating crosstalk). The four scenarios come from the fact that stage 1 can have 1 or 2 compensating elements, and stage 2 can have 1 or 2 compensating elements (resulting in four combinations).

For all scenarios addressed below, it is assumed that all capacitors are built with the same core thickness and, the same dielectric material, and are subject to the same over-etching or under-etching during PCB manufacturing. This assumption is reasonable if the capacitors are physically located near each other during PCB manufacturing (within a few inches). Additionally, these results assume no edge

effects or other variations to the capacitance (i.e., equation 1 holds). These results can easily be slightly modified to account for the change in capacitance caused by capacitor edge effects, and/or other effects caused by distributed electrical parameters.

Scenario 1: 1 Capacitor in Stage 1, and 1 Capacitor in Stage 2

For this scenario, there is 1 capacitor in stage 1 and 1 capacitor in stage 2. The stage 1 capacitor is larger than the stage 2 capacitor. Due to the fact the stage 1 capacitor is larger, its area will vary more than the stage 2 capacitor for the same etching variation. Therefore, to minimize the change in the stage 1 capacitor **53** (see FIG. 16 for an example), it should be a square (with side dimensions X). The stage 2 capacitor **55** is a rectangle with dimensions Y and Z. The areas of both capacitors are set by the designer to achieve the necessary performance (area of A for the first stage, and B for the second stage).

Therefore, since the effective areas of overlap (A (stage 1) and B (stage 2)) of these capacitors are known,

$$X^2 = A, \quad (5)$$

and

$$Y \cdot Z = B. \quad (6)$$

Since the net capacitance (proportional to net area,  $A_{\text{net}}$ ) between them is also set by the designer,

$$A_{\text{net, scenario 1 (ideal case)}} = A - B = X^2 - Y \cdot Z. \quad (7)$$

Additionally, if we want to minimize the effect of etching, we can try to achieve the same  $A_{\text{net}}$  with an over-etching or under-etching of E (E will be positive with under-etching and negative with over-etching). This leads to the equation

$$A_{\text{net, scenario 1 (with etching error E)}} = (X+E)^2 - (Y+E) \cdot Z = A - B = X^2 - Y \cdot Z. \quad (8)$$

Solving equations 5 with respect to X gives

$$X = \sqrt{A}. \quad (9)$$

Substituting this value of X into equation 8 gives

$$(\sqrt{A}+E)^2 - (Y+E) \cdot Z = (\sqrt{A})^2 - Y \cdot Z, \quad (10)$$

which can be expanded to

$$A + 2 \cdot E \cdot \sqrt{A} + E^2 - Y \cdot Z - Z \cdot E - Y \cdot E - E^2 = A - Y \cdot Z. \quad (11)$$

Cancelling identical terms on both sides of equation 11 gives

$$2 \cdot E \cdot \sqrt{A} - Z \cdot E - Y \cdot E = 0. \quad (12)$$

Dividing both sides of equation 12 by E yields

$$2 \cdot \sqrt{A} - Z - Y = 0. \quad (13)$$

Substituting  $Y = B/Z$  (from equation 6) into equation 13, multiplying both sides of equation 13 by  $-1$ , and rearranging the terms, yields

$$Z - 2 \cdot \sqrt{A} + B/Z = 0. \quad (14)$$

Multiplying both sides of equation 14 by Z gives

$$Z^2 - 2 \cdot Z \cdot \sqrt{A} + B = 0. \quad (15)$$

This is a quadratic equation which can be solved for Z as

$$Z = \sqrt{A} \pm \sqrt{A - B}. \quad (16)$$

Similarly solving equation 13 for Y gives

$$Y = \sqrt{A} \mp \sqrt{A - B}. \quad (17)$$

Also,  $X = \sqrt{A}$  (from equation 5).

Note that depending on the sign used in equation 16, the opposite sign must be used in equation 17. Also note that in

## 11

equations 9, 16, and 17 the etching factor, E, is no longer in these equations; consequently, for any change in etching, these equations hold true. Thus, the net capacitance will not change given any change in etching. Therefore, for a two-stage compensating scheme having a first stage compensating capacitor of area  $A=X^2$ , a second stage of  $B=Y*Z$  (rectangle), with Anet, scenario 1 (with etching error E)=Anet, scenario 1 (ideal case), equations 9, 16, and 17 can be used to determine X, Y, and Z.

Scenario 2: 2 Capacitors in Stage 1, and 2 Capacitors in Stage 2

In this scenario there are two capacitors in stage 1, and 2 capacitors in stage 2. See FIG. 17 for a visualization of these capacitors. Each capacitor can have a different size. The net area of the two capacitors 61 and 65 in stage 1 is larger than the net area of the capacitors 63 and 67 in stage 2. Following the same logic as was done in scenario 1, assuming that the capacitors of stage 1 are squares and the capacitors of stage 2 are rectangles (A, B, C, and D are areas that are given),

$$X*X=A, \quad (18)$$

$$W*W=C, \quad (19)$$

$$Y*Z=B, \quad (20)$$

and

$$T*U=D. \quad (21)$$

For this scenario, Anet is equal to

$$A_{\text{net, scenario 2}}=A+C-B-D. \quad (22)$$

Since the net area needs to be the same before and after any etching effects E, substituting equations 18 to 21 into equation 22,

$$A_{\text{net, scenario 2 (ideal case)}}=X^2+W^2-Y*Z-T*U, \quad (23)$$

and

$$A_{\text{net, scenario 2 (with etching error E)}}=(X+E)^2+(W+E)^2-(Y+E)(Z+E)-(T+E)(U+E). \quad (24)$$

Following a similar derivation as scenario 1, Y and Z can be solved for as

$$Y=A+\sqrt{C-(T+U)/2} \pm \sqrt{((T+U)/2-\sqrt{A}-\sqrt{C})^2-B}, \quad (25)$$

$$Z=\sqrt{A+\sqrt{C-(T+U)/2}} \mp \sqrt{((T+U)/2-\sqrt{A}-\sqrt{C})^2-B}, \quad (26)$$

and

$$X=\sqrt{A}, W=\sqrt{C}, \text{ and } T*U=D \text{ (from equations 18, 19, and 21).}$$

Note that Y and Z can both be interchanged.

Thus, for given areas A, B, C, and D and given dimensions T and U, one can find a Y and Z that eliminate the effect of etching. Equations 25 and 26 are the most important and most universal equations for this as all other scenarios can be derived from these equations. Note that equations 16 and 17 can be derived from equations 25 and 26 by setting C, T, and U equal to zero.

Under the special case where areas  $A=C$  and  $B=D$ , one can use equations 16 and 17 derived in scenario 1.

Scenario 3: 2 Capacitors in Stage 1, and 1 Capacitor in Stage 2

In this scenario, one can use equations 25 and 26 but set T and U (and consequently D) equal to zero.

Scenario 4: 1 Capacitor in Stage 1, and 2 Capacitors in Stage 2

## 12

In this scenario, one can use equations 25 and 26 but set C (and consequently W) equal to zero.

FIG. 18 is a fragmentary side view of a communication jack 78 with a mated communication plug 6 in accordance with an embodiment of the present invention.

Communication jack 78 includes, among other things, a housing 79 into which a communication plug 6 enters, a horizontal rigid PCB 84, and a vertical rigid PCB 82. A portion of communication jack 78 is expanded to illustrate the mechanical and electrical functionalities of the communication jack.

In the second embodiment, contact between the horizontal rigid PCB 84 and the PICs of the communication jack is made through a clip-on style contact 90. In this embodiment, when the plug contacts 12 press downward on the contact elements 88 of the PICs, the PICs rotate around a centerline contact radius 92. Operation is as described above, with the contact normal force resulting from the resistance of spring elements 94. The PCBs 82, 84 can have compensation the same as, or similar to, that previously described for PCBs 50, 60, respectively.

As described above, the contact elements 88 are respectively connected to the spring elements 94 via electrically insulating elements 96. In some embodiments, the electrically insulating element 96 may be omitted if the spring element 94 is made of or coated with an insulating material, such as insert-molded plastic or a powder coating.

In the foregoing descriptions, the communication jack has been described as an RJ45 communication jack, such as a CAT6 or CAT6A jack. However, the invention described here is not limited to such an application. It may be applied just as well in other types and/or configurations of jacks or couplers. Other examples are possible as well.

The present invention may be used in a communication system such as that depicted in FIG. 19. Communication system 102 is shown comprising foil labels 100a and 100b, a communication plug 6, communication jacks 106, communication cables 108, and equipment 110. Communication jack 106 may be any of the jacks, or combinations thereof, as described herein. While FIG. 19 depicts a particular number of communication cables 108, the number is purely one example, and more or fewer communication cables are possible as well. Equipment 110 is illustrated as a patch panel, but is not so limited. The equipment 110 may be either passive or active equipment. Examples of passive equipment include modular patch panels, punch-down patch panels, couple patch panels, wall jacks, etc. This list is not meant to be limiting, as other types of passive equipment are possible as well. Examples of active equipment include Ethernet switches, routers, servers, physical layer management systems, power-over-Ethernet equipment as often found in data centers and telecommunications rooms, and security devices (including cameras and sensors) and door access equipment. Other examples of active equipment include workstation peripherals, such as telephones, fax machines, computers, printers, and others. This list is not meant to be limiting, as other types of active equipment are possible as well. The communication system 102 may further include cabinets, racks, cable management and overhead routing systems, and other such equipment.

The communication cables 108 may be unshielded twisted pair (UTP) cables, and more particularly, Category 6A cables that can operate at 10 GB/s. However, the present invention may be equally applied to or implemented in a variety of communications cables. Examples of possible communications cables include shielded cables, unshielded cables, CAT5E, CAT6, CAT6A, CAT7, CAT7A and other twisted

13

pair Ethernet cables, and others. This list is not meant to be limiting, as other types of cables are possible as well.

Some of the communication cables **108** may be terminated directly into the equipment **110**, and others may be terminated into the communication jacks **106**, communication plugs **6**, or combinations thereof. The use of communication jacks **106** may eliminate the need for the foil labels **100**, and may further improve ANEXT, as described above. Further, the communication cables **108** may be processed into looms, or bundles, of cables and may be processed into preterminated looms.

Communication cables **108** may be used in a variety of structured cabling applications such as patch cords, zone cords, backbone cabling, and horizontal cabling, though the present invention is not limited to such applications. In general, the present invention may be used in military, industrial, telecommunications, computer, data communications, and other cabling applications.

A method of manufacturing the communication jack described above is also contemplated. The method may include providing a PCB that includes one or more crosstalk compensation circuits, and contacting a PIC to a contact on the PCB. The PIC may, as described above, include a spring element, a contact element pivotally connected to the spring element, and an electrically insulating element that connects the contact element to the spring element. As in the above-described embodiments, the PCB may be a rigid PCB, and the contact on the PCB may contact the PIC at the interface of the contact element and the electrically insulating element.

FIGS. **20-29** illustrate another embodiment of the present invention. The embodiment of RJ45 jack **138** is similar to the previously described jack, but eliminates the PIC's plastic overmolded sleeves which mechanically engage the springs for the PICs, which modifies the wiping contacts to reduce the chance of hi-pot failures, and which provides a comb structure in the front sled to constrain the PICs. In place of the overmolded sleeves on the PICs, the RJ45 jack **38** of FIGS. **20-29**, includes a front sled with breakaway plastic insulator caps which cover the tips of the springs, and breakaway from the sled, when the springs are inserted into the sled. In the present invention, the wiping contacts on the horizontal circuit board have been modified to eliminate the upright arms that extend beyond the footprint of the PICs, and the PIC/spring/wiping contact structures have modified so that the PICs/springs/wiping contacts have a coincident contact point at the insulator caps.

An exploded view of jack **138** can be seen in FIG. **20**. Jack **138** includes a front housing **48**, front sled assembly **142**, vertical rigid PCB **50**, insulation displacing contacts (IDCs) **52**, IDC support structure **51**, rear housing **54**, and termination cap **56**.

Like the jack previously described, jack **138** uses two rigid circuit boards **50**, **60**, and a separate spring **156** (FIG. **21**) mechanically actuates the PICs **158**. In the present invention, PICs **158** do not require a micro-overmolding operation to achieve electrical insulation from spring **156**. Plastic insulator caps **160** cover the tips of spring **156**, providing the necessary insulation. FIG. **21** shows this interaction in front sled assembly **142**. Note that the plastic sled **162** has been exploded away to better show the location of spring **156**. FIG. **22** shows an exploded view of front sled assembly **142**, which includes horizontal rigid PCB **60**, spring **156**, PICs **158**, insulator caps **160** which are initially part of plastic sled **162**, PCB **60** to PIC contacts **164**, and 90° PCB **60** to PCB **50** contacts **166**.

FIG. **23** shows a cross-sectional view of an RJ45 plug **6** inserted into jack **138**. The plug contacts **12** of plug **6** make electrical contact with PICs **158** of jack **138**. As PICs **158** are

14

pressed down by plug contacts **12**, spring **156** flexes/compresses and presses back against PICs **158**. This provides sufficient normal force between plug contacts **12** and PICs **158** to ensure proper electrical bond. Notice that PCB to PIC contact **164** is pressed between insulator cap **160** and PIC **158**. This ensures that the interface between PIC **158** and PCB to PIC contact **164** is under compression and makes a good electrical connection. This eliminates the need for wiping contacts with arms previously described. Because PCB to PIC contacts **164** do not extend beyond the sides of PICs **158** (as shown in FIG. **24**), hi-pot (high potential testing) risk is mitigated as compared to the wiping contacts previously described. Formed ends **159** of PICs **158** are captured in slots **161** of sled **162**.

FIG. **25** shows an isometric view of spring **156** being assembled to plastic sled **162**. A section view in FIG. **26** shows spring **156** approaching plastic sled **162**. Insulator caps **160** are molded into plastic sled **162**. In FIG. **27**, spring **156** approaches plastic sled **162** where tips of spring **156** engage insulator caps **160**. Spring **156** continues driving upward during assembly, breaking the Insulator caps **160** free from plastic sled **162** as shown in FIG. **28**. By combining the assembly of spring **156** to plastic sled **162**, and insulating the PICs **158** from spring **156**, into one operation, the micro-insert molding operation is eliminated, reducing the overall cost of the jack.

Alternatively, front sled assembly **142** can be modified to eliminate breakaway insulating caps **160**. It may be advantageous to use an alternative front sled assembly **172** as shown in FIG. **29**. In front sled assembly **172**, PIC **159** and PCB to PIC contact **165** are supported by a plastic cantilever **174** molded directly into front sled **176**. This allows for the elimination of plastic insulating caps **160**. As PIC **159** rotates, plastic cantilever **174** flexes downward. Spring **178** reinforces plastic cantilever **174** and pushes back to provide the necessary force on PIC **159**.

FIGS. **30-32** illustrate another embodiment of the present invention. RJ45 jack **238** (FIG. **30**) reduces cost by eliminating the secondary spring component as well as simplifying assembly by eliminating the PIC's plastic overmolded sleeve, and electrical performance is improved by shortening the electrical distance between the plug contact and the first PCB. Furthermore, PIC comb structures are designed in the front sled.

An exploded view of jack **238** is shown in FIG. **30**. Jack **238** is comprised of a front housing **48**, front sled **242**, PICs **244**, front PCB **60**, PCB to PCB contacts **248**, vertical PCB **50**, insulation displacing contacts (IDCs) support structure **51**, IDCs **52**, rear housing **54**, and termination cap **56**.

Jack **238** of FIGS. **30-32** uses two rigid circuit boards **50**, **60**. However, jack **238** does not decouple the mechanical spring functionality from the PIC. Instead PICs **244** flex and create the necessary normal force at the interface between the PIC **244** and plug contact **12** to ensure a proper electrical bond. This design is attainable if PICs **244** are fabricated from sufficiently thin layers **44a-44c** of material so as not to plastically deform during plug insertion. Thicker materials would experience higher stresses during deflection and would not spring back to its original nominal position, drastically reducing the reliability of the jack. However, a single thin PIC **244** does not provide enough normal force at the interface between PIC **244** and plug contact **12**. Therefore multiple thin PIC layers **44a**, **44b**, and **44c** are stacked and the cumulative group provides the necessary normal force. PIC layers **44a**, **44b**, and **44c** do not have to be of the same material. Only PIC layer **44a** that engages plug contact **12** needs to be of a material that has high electrical conductivity, such as phos-

15

phor-bronze plated with nickel, then plated with gold. PIC layers **44b** and **44c** can be fabricated from a different material, such as a spring steel to provide the mechanical normal force requirement. The thickness of the individual PICs **44a-44c** can be 0.001-0.005 inches, and preferably in the range of 0.002-0.003 inches. Although three layers of individual PICs **44a-44c** are shown each PIC **244** can have 2-7 layers, and preferably 3-5 layers.

PICs **244** are not laminated PICs; instead they are free-body layered PICs. Each of the layers of fixed end **264** of PIC **244** (see FIG. **32**) are constrained by PCB **60** and a solder joint, or alternatively a press-fit joint. However, each of layers **44a-44c** can move relative to each other in free section **266** of PIC **244**. PICs **244** are laterally constrained in part by comb **243** on front sled **242**.

FIG. **31** shows a section view of an RJ45 plug **6** inserted into jack **238**. The plug contact **12** of plug **6** makes electrical contact with PIC **44a** of jack **238**. As PICs **244** flex down by plug contact **6**, a normal force is generated at the interface to ensure proper electrical bond. Front sled **242** is located atop front PCB **60** and is wedge-shaped to control the angle at which PCB **60** sits in the assembly of jack **238**. Also, front sled **242** backs up PICs **244** and has bend radius control **260** to ensure proper bending of PICs **244**, which will distribute stresses evenly and prevent localized stress concentrations that could lead to material yield.

In addition to simplified assembly, electrical performance benefits can be achieved by using the layered PIC design of jack **238**. FIG. **32** shows the electrical distance of PIC **244**, which is defined as total signal length from nominal plug contact **262** as defined in IEC 60603-7-1 to front PCB **60**. The electrical distance of jack **238** is 0.162". This translates to reduced PIC coupling and improved electrical performance.

FIGS. **33-36** illustrate another embodiment of the present invention. RJ45 jack of FIGS. **33-36** has improved PICs, PIC staggering, and jack housing features to improve the PICs/PIC interface in the jack to make the PICs robust and relatively low cost.

Referring now to FIGS. **33-36**, RJ45 jack **330** includes PICs **332** which are inserted into bottom side **336** of PCB **60A** as shown into FIG. **34**. As with PICs **244**, PICs **332** are layered PICs with a contact layer and at least one spring layer. Sled **242** includes comb structure **243** to help constrain PICs **332** when they are depressed by plug **6**, as is also shown in FIG. **30**. Shoulder features **338** are present on PICs **332** to prevent PICs **332** from traveling too far during insertion or pulling out of top side **340** of PCB **60A** during cycling or vibration. Press fit features **342** are located on PICs **332** to create a mechanical friction hold as well as ensure sufficient continuity between PICs **332** and PCB **60A**. Press fit features **342** are shown in FIG. **34** with a stamped eye of the needle type of design. PCB **60A** can have compensation the same as, or similar to, that previously described for PCB **60**.

Because PICs **332** are inserted into bottom side **336** of PCB **60A**, the width of PICs **332** must be less than the diameter of holes **344**. Therefore, to increase the width of PICs **332**, holes **344** must also increase in diameter. Increasing PIC **332** width is mechanically and electrically advantageous as it increases PIC **332** stiffness, makes assembly handling easier, and provides lower electrical resistance. As the hole diameter increases, the edges of adjacent holes get closer in proximity unless holes **344** are staggered as shown in FIG. **35**. It is important to maintain sufficient separation **346** between hole **344** edges because hi-pot failures will occur if they get too close.

FIG. **36** shows a section view of jack **330**. PICs **332** cannot be pulled out of PCB **60A** through top side **340** because of

16

shoulder features **338**. To eliminate PICs **332** from pulling out of PCB **60A** from the bottom, a ledge **348** has been added to front housing **350**. Ledge **348** reduces the mechanical frictional requirement of press fit features **342** which increases overall robustness of the interface.

Alternative embodiments of features **342** may include compliant shape made using shearing, forming, or coining operations individually or combined.

Other embodiments of the present invention can include PCB **60A** and PCB **50A** (see FIGS. **37-43**). In this embodiment the present invention uses two unique stack-ups for both the rigid PCB **60A** and the rigid PCB **50A**. The rigid PCB **60A** uses a 4-layer stack-up that contains 2 mil cores on the outer layers. This allows trace routings on all layers giving the engineer more flexibility, in addition to placing the capacitors as close as possible to the plug. Finally, the rigid PCB **50A** uses a 2-layer stack-up. The reason a 2-layer stack-up was used is that the vertical board **30** has no capacitors on it. Therefore, it is used to connect the PCB to PCB contacts to the IDCs and a 2-layer board is a cost effective method of doing that. Each of these designs is 0.062" thick, and the rigid PCB **60A** stackup is shown in the middle table of FIG. **37** and the vertical board **50A** stackup is shown in the bottom table of FIG. **37**.

The schematic for rigid PCB **60A** is shown in FIG. **38**. The artwork for each layer is shown individually in FIG. **39**, and together in a single isometric view in FIG. **40**. A summary of the compensation on rigid PCB **60A**:

- 1) Crosstalk compensation with a polarity opposite that of the plug for pair combination 45-36 is provided by pad capacitors C35 and C46. The surface area for both pad capacitors is 0.000576 inches<sup>2</sup> ( $\pm 20\%$ ), resulting in a capacitance of approximately 0.9 pF.
- 2) Crosstalk compensation with a polarity opposite that of the plug for pair combination 36-12 is provided by pad capacitor C26. The surface area for these pad capacitors is 0.000676 inches<sup>2</sup> ( $\pm 20\%$ ), resulting in a capacitance of approximately 0.65 pF.
- 3) Crosstalk compensation with a polarity opposite that of the plug for pair combination 36-78 is provided by pad capacitor C37. The surface area for these pad capacitors is 0.001369 inches<sup>2</sup> ( $\pm 20\%$ ), resulting in a capacitance of approximately 1.1 pF.
- 4) Crosstalk having the opposite polarity of the net crosstalk caused by the plug for pair combination 45-78 is provided by pad capacitor C58 connected between the 5 and 8 PIC vias. The area of pad capacitor C58 is 0.000225 inches<sup>2</sup> ( $\pm 20\%$ ), resulting in a capacitance of approximately 0.3 pF.
- 5) Crosstalk having the opposite polarity of the net crosstalk caused by the plug for pair combination 45-12 is provided by pad capacitor C14 connected between the 1 and 4 PIC vias. The area of pad capacitor C14 is 0.000121 inches<sup>2</sup> ( $\pm 20\%$ ), resulting in a capacitance of approximately 0.2 pF.

The schematic for the rigid PCB **50A** is shown in FIG. **41**. The artwork for each layer is shown individually in FIG. **42**, and together in a single isometric view in FIG. **43**. Rigid PCB **50A** is a 2-layer circuit board with no capacitors on it. It serves the purpose of connecting the PCB to PCB contacts **28** to the IDCs **34**. The reason a 2-layer circuit board was used is that it offers considerable cost savings over a 4-layer rigid board.

An additional embodiment is to have the same stack-up type for the rigid PCB **60A** and rigid PCB **50A** (4-layer and 2-layer, respectively), but with a different overall thickness (different than 0.062"). Another embodiment includes a rigid

17

PCB 60A with a different thickness than the overall thickness for rigid PCB 50A. Another embodiment includes a 4-layer stack-up for rigid PCB 50A. The 4-layer stack-up can be from the top table in FIG. 37 or the 4-layer stack-up used by the rigid PCB 60A of the present invention.

Any of the embodiments of PCBs 50A and 60A can replace the PCBs 50 and 60, respectively.

While this invention has been described as having a preferred design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

We claim:

1. A communication connector, comprising:
  - a housing having an aperture for receiving a communication plug;
  - a plurality of plug interface contacts connected to said housing and at least partially within said aperture, at least one of said plurality of plug interface contacts (PICs) including a contact element, a spring element, and a connecting element connecting said contact element to said spring element.
2. The communication connector of claim 1, wherein said connecting element is an insulating element.
3. The communication connector of claim 1, further including a circuit board at least partially within said housing.
4. The communication connector of claim 3, further including a plurality of PIC contacts in electrical communication with said circuit board.
5. The communication connector of claim 4, wherein each said contact element of said plurality of PICs directly contacts a respective one of said plurality of PIC contacts.
6. The communication connector of claim 3, wherein said circuit board is a rigid circuit board.
7. A communication system, comprising:
  - an electrical equipment; and
  - a communication connector connected to said electrical equipment, said communication connector including a housing having an aperture for receiving a communication plug,
  - a plurality of plug interface contacts connected to said housing and at least partially within said aperture, at least one of said plurality of plug interface contacts (PICs) including a contact element, a spring element, and a connecting element connecting said contact element to said spring element.
8. The communication system of claim 7, wherein said connecting element is an insulating element.
9. The communication system of claim 7, further including a circuit board at least partially within said housing.
10. The communication system of claim 9, further including a plurality of PIC contacts in electrical communication with said circuit board.
11. The communication system of claim 10, wherein each said contact element of said plurality of PICs directly contacts a respective one of said plurality of PIC contacts.
12. The communication system of claim 9, wherein said circuit board is a rigid circuit board.
13. A communication connector comprising:
  - a housing having an aperture for receiving a communication plug; and
  - a plurality of plug interface contacts (PICs) positioned at least partially within said aperture, at least one of said

18

plurality of PICs including a contact element, a spring element, and an insulating element positioned between said contact element and said spring element.

14. The communication connector of claim 13 further comprising:

- a printed circuit board (PCB) positioned longitudinally within said communication connector and extending at least partially into said aperture; and
- a plurality of circuit board contacts extending from said PCB, at least one of said circuit board contacts making electrical contact with said contact element of said at least one of said plurality of PICs when a corresponding connector is mated to said communication connector.

15. The communication connector of claim 14, wherein said at least one of said circuit board contacts extends vertically from said PCB.

16. The communication connector of claim 14, wherein said at least one of said circuit board contacts is a wiping contact.

17. The communication connector of claim 14, wherein said at least one of said circuit board contacts includes a first and a second contact wall extending vertically from said PCB, and wherein at least a portion of said contact element of said at least one of said plurality of PICs is positioned between said first and said second contact walls when said communication connector is mated to said corresponding connector.

18. A communication system comprising:

- electrical equipment; and
- a communication jack connected to said electrical equipment, said communication jack comprising:
  - a housing having an aperture for receiving a communication plug; and
  - a plurality of plug interface contacts (PICs) positioned at least partially within said aperture, at least one of said plurality of PICs including a contact element, a spring element, and an insulating element positioned between said contact element and said spring element.

19. The communication system of claim 18, wherein said communication jack further comprises:

- a printed circuit board (PCB) positioned longitudinally within said communication jack and extending at least partially into said aperture; and
- a plurality of circuit board contacts extending from said PCB, at least one of said circuit board contacts making electrical contact with said contact element of said at least one of said plurality of PICs when a corresponding plug is mated to said communication jack.

20. The communication system of claim 19, wherein said at least one of said circuit board contacts extends vertically from said PCB.

21. The communication system of claim 19, wherein said at least one of said circuit board contacts is a wiping contact.

22. The communication system of claim 19, wherein said at least one of said circuit board contacts includes a first and a second contact wall extending vertically from said PCB, and wherein at least a portion of said contact element of said at least one of said plurality of PICs is positioned between said first and said second contact walls when said communication jack is mated to said corresponding plug.

23. A communication connector comprising:

- a housing having an aperture for receiving a communication plug;
- a plurality of plug interface contacts (PICs) positioned at least partially within said aperture;

## 19

a printed circuit board (PCB) positioned longitudinally within said communication connector and extending at least partially into said aperture; and  
 a plurality of circuit board contacts extending from said PCB, at least one of said circuit board contacts making electrical contact with at least one of said plurality of PICs when said communication plug is mated to said communication connector,  
 wherein said at least one of said circuit board contacts is a wiping contact.

**24.** The communication connector of claim **23**, wherein said at least one of said circuit board contacts extends vertically from said PCB.

**25.** The communication connector of claim **23**, wherein said at least one of said circuit board contacts includes a first and a second contact wall extending vertically from said PCB, and wherein at least a portion of said at least one of said plurality of PICs is positioned between said first and said second contact walls when said communication connector is mated to said corresponding connector.

**26.** A communication system comprising:

electrical equipment; and

a communication jack connected to said electrical equipment, said communication jack comprising:

## 20

a housing having an aperture for receiving a communication plug;

a plurality of plug interface contacts (PICs) positioned at least partially within said aperture;

a printed circuit board (PCB) positioned longitudinally within said communication connector and extending at least partially into said aperture; and

a plurality of circuit board contacts extending from said PCB, at least one of said circuit board contacts making electrical contact with at least one of said plurality of PICs when a corresponding connector is mated to said communication connector, wherein said at least one of said circuit board contacts is a wiping contact.

**27.** The communication system of claim **26**, wherein said at least one of said circuit board contacts extends vertically from said PCB.

**28.** The communication system of claim **26**, wherein said at least one of said circuit board contacts includes a first and a second contact wall extending vertically from said PCB, and wherein at least a portion of said at least one of said plurality of PICs is positioned between said first and said second contact walls when said communication connector is mated to said corresponding connector.

\* \* \* \* \*